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JOURNAL OF THE AMERICAN WELDING SOCIETY

VOLUME XII | JANUARY 1933 | NUMBER 1

The Journal

Beginning with this issue an attempt is being made by the Meetings and Papers Committee to enlarge the scope and usefulness of the JOURNAL. New departments have been added. Still others are under consideration.

Members of the Society and subscribers are invited to send in their suggestions for further improvements. Articles which may be classified under these various department heads are also invited.

Bound Volume Journal

In order to allow the members ample time to get in their twelve issues of the JOURNAL to the binder to be bound, the Society is extending the time to February 15th.

President Talks on Welding

The President of the AMERICAN WELDING SOCIETY has recently delivered addresses at Cornell University, Rochester Branch of the A. S. C. E., University of Toronto and the Royal Military College. He has talked on welding with particular reference to erecting of steel buildings and strengthening of steel bridges by welding.

Second Annual Welding Conference

The Ohio State University will hold its Second Annual Welding Conference in the Industrial Engineering Building on February 23 and 24, 1933. Manufacturers of welding equipment and supplies have been requested to cooperate.

Fourth Annual Greater New York Safety Conference

The Fourth Annual Greater New York Safety Conference will be held March 1 and 2, 1933, at the Hotel Pennsylvania, New York, under the auspices of the Metropolitan Chapter of the American Society of Safety Engineers, Engineering Division of the National Safety Council.

During the two days there will be sixteen sessions devoted to various aspects of the safety problem, and on the evening of the first day a banquet will be held. Sessions will be held both morning and afternoon, the morning sessions beginning at 10:00 A.M. and the afternoon sessions at 2:15 P.M.

There will be no registration or admission fee and no obligation of any kind involved.

Welding Meeting in Quebec

Mr. Jules Blanchard, as representative of the AMERICAN WELDING SOCIETY in the Quebec District, called a meeting on November 28th, at the Technical Institute, for the purpose of recruiting members for the Canadian Section of this Society, to be formed here. Among those present were R. Bergeron, of Canadian Industries, Ltd.; L. Lefebvre, S. W. & P. Co.; F. Bordeleau, Shawinigan Chemicals; D. Lord, Shawinigan Chemicals; J. Paris; Shawinigan Laboratories; M. Marineau, Aluminum Co. and a few others interested in the art of welding.

Mr. Blanchard explained the aims and objects of the Society and his intention to form a branch in Shawinigan Falls. All those present were greatly interested in the project but it was unanimously decided to postpone until a later date the formation of a local branch.

In the meantime, Mr. Blanchard has undertaken to give free information on any process of welding, at the Technical School, until the end of the term next year, and all those interested will kindly communicate with him. There will be a meeting held every month at the Technical Institute, when important papers will be presented and discussed. The next meeting was scheduled for December 28th, when Mr. E. Bordeleau presented a paper entitled, "Electric Welding Using the Fleetweld Shielded Arc Electrode."

Youngstown Holds Welding Meeting

The first of a series of meetings to be held in the Ohio Edison Auditorium, Youngstown, Ohio, under the auspices of local manufacturers, was held on Wednesday evening, December 7th, at which were present over 200 men.

Concentration of stress due to poor design joints and corrosion of welds causing many weld failures, was the nucleus of a talk given by Robert E. Kinkead, noted welding engineer.

Mr. E. E. Tross, Works Manager of the United Engineering & Foundry Co., Youngstown, Ohio, acted as Chairman. This meeting was sponsored by The Lincoln Electric Company.

After the meeting he appointed Mr. Krehl of the Youngstown Sheet & Tube Co., Mr. W. Kelley of the Republic Steel Corp., Mr. F. L. Lindenmuth of the W. B. Pollock Co., Mr. Grover Hughes of the Truscon Steel Co. and Mr. H. Watson of the Youngstown Welding Co., as members of a committee to assist him with future meetings.

It is their plan to hold meetings about every six weeks throughout the winter months.

THE SIGNIFICANCE OF ENGINEERS' DAY

By Joseph Harrington

An occasion on which the best minds of the world foregather to exchange ideas, cannot fail to have the greatest significance for all those interested in the subject touched upon. This is especially so when the agenda provides a directional influence toward those things so intimately touching our every-day lives, as will be the case on "Engineers' Day" at A Century of Progress next June.

On this day, especially set apart and dedicated to the engineer, will be presented to the world a marvelous series of demonstrations of the wonders wrought by Science since the founding of Chicago. That engineers may see the fruits of their own efforts, every mechanical, electrical and physical piece of apparatus will be in service, producing the results that have made this the Age of Wonder. Exhibitors, realizing the critical nature of their audience, will be on their toes, that their equipment may show to best advantage to the thousands of understanding visitors who will be there. And thousands will be there, for this is the great day of the engineer. Nineteen of the national societies, with a membership of one hundred thousand, have set this day and week for a world-wide conclave. Great engineers from all over the world will come to see the achievements of American genius.

Conferences of the several Societies will listen to the reading of papers on scientific subjects by recognized authorities, and discussions by other equally famous engineers. No one, either directly or indirectly affiliated with industry, can afford to miss this opportunity. With the World for an audience, the best thought of the best minds will characterize the discussions. Undoubtedly some permanent record will be made, and the history of science enriched by the master contributions of that week.

The part played by engineers in the modeling of civilization will be held up to the gaze of the world. This marvelous opportunity offered to a group of men ordinarily self-effacing shall not be passed without adequate recognition. Man owes an incalculable debt to the engineer, the recognition of which will serve to dignify and sustain the position of the profession and implant in the minds of men some idea of his service to humanity. This day will indeed signify that the engineer is the mainspring of human progress, gladly serving his fellow men and ever ready to heed the call to new and better things.

SECTION ACTIVITIES

BOSTON

A large number of members and guests attended the December 9th meeting of the Boston Section in the rooms of the Engineering Societies, to learn more about repairing bridges with electric welding. Mr. Doolittle of the Leake and Nelson Company, Bridgeport, Connecticut, presented the paper in the absence of Mr. A. G. Leake, and in the discussion of this subject used many interesting slides showing actual bridge repairs by welding. A model of the method devised by Mr. Leake for reinforcing bridge members was shown. To quote from the paper, "Although the application of arc welding to this class of work is new, it has rapidly come to the front, and is today a recognized method of making bridge repairs."

It was planned to hold the next meeting of the Section at the Massachusetts Institute of Technology on the evening of Friday, January 20, 1933. Details of this meeting will be given in the regular notices.

CHICAGO

The December meeting of the Chicago Section was held on the 16th. "Training Method for Welders and Inspectors, Commonwealth Edison Company" was the subject of the talks given by J. S. Strong and J. F. Sullivan, Jr. Mr. Strong and Mr. Sullivan outlined the methods used in training these men in the fundamentals of welding, metallurgy, etc.

"The Welding of Aluminum and Its Alloys, by both the Electric and Gas Process," was the subject of the talk by G. O. Hoglund, in charge of welding at the U. S. Aluminum Company, New Kensington, Pa.

The present status of the proposed new Chicago building code, which allows welding under A. W. S. standards, was outlined by Mr. J. I. Banash.

CLEVELAND

Four 15-minute talks were given at the January 11th meeting of the Cleveland Section. Mr. A. F. Davis, Vice-President of The Lincoln Electric Company spoke on "What a Membership in the A. W. S. Means." Mr. R. D. Randall, President, Cleveland School of Welding, Inc., spoke on "Technocracy-Welding." Mr. W. T. Alleman, Engineer, Graduate Zurich (Switzerland) University, spoke on "Welding in Europe." Mr. E. R. Benedict, President, United District Heating Co., spoke on "Use of the Metal Spray in the Welding Industry." Lively discussion followed each paper.

LOS ANGELES

The object of the December 15th meeting of this Section was to further the use of welding of piping. Mr. G. T. Brooke, Manager of Industrial Division, Crane Company, presented a paper on "Welding of Industrial Piping." Mr. Brooke's paper was illustrated with slides and motion pictures. Representatives of the following firms were present to take part in the discussion: The C. F. Braun Co., The Grinnell Co., The Fluor Corp., Procter and Gamble Co. and The Midwest Piping & Supply Company.

NEW YORK

A joint meeting of the New York Section, AMERICAN WELDING SOCIETY with the Machine Shop Practice and Iron and Steel Divisions of the American Society of Mechanical Engineers, was held on January 10th. "Welded Construction of Heavy Mechanical and Industrial Equipment" was the general presentation of the subject. Mr. A. E. Gibson, Vice-President, Wellman Engineering Co., presented a paper on "Application of Welding to the Manufacture of Heavy Mechanical Equipment," and Mr. H. G. Marsh, Chairman, Trade Research Committee, Carnegie Steel Co., spoke on "Welded Design and Construction of Heavy Industrial Equipment." Discussion followed.

DETROIT

"Welding Day" under the auspices of the Detroit Section, in conjunction with the Highway and Building Congress, was held on January 18th at Detroit City Airport. "Use of Welding by the Detroit Edison Co." was presented by Col. A. S. Douglass, Construction Engineer, Detroit Edison Co. Col. Douglass discussed the practical solution by welding of problems in the design of power plants, sub-stations and piping. His talk was illustrated.

Mr. Joseph Matte, Jr., Construction Engineer, Albert Kahn, Inc., Architects and Engineers, spoke on "Welding in Action." Mr. Matte, Jr., gave a non-technical exposition of welding as applied to highways and buildings, fully illustrated by slides, moving pictures and actual welding demonstrations.

PHILADELPHIA

The January meeting of the Philadelphia Section was held on the 16th in the Auditorium of the Engineers' Club. Mr. John J. Crowe of the Air Reduction Sales Company, spoke on "Testing of Welds." Mr. Crowe's paper was very interesting and a lively discussion followed.

SAN FRANCISCO

"Pipe Welding" was the subject of the December 16th meeting of the San Francisco Section. Mr. C. B. Leahy, Supervisor of the Applied Engineering Department of the Air Reduction Sales Company, presented a paper entitled, "Pipe Welding—Welder Fittings—Welder Training." Mr. Leahy's paper was illustrated by lantern slides which showed the progress being made in various parts of the country by the use of welding in buildings.

The Linde Air Products Co. presented a film, "Panel Heating." This film showed the installation of the panel heating system in the new British Embassy in Washington, D. C. This system involves the use of heating coils concealed in the ceiling and side walls. The construction is welded throughout to insure permanently leak-proof joints.

EMPLOYMENT SERVICE BULLETIN

POSITIONS VACANT

United States Civil Service Examination

The United States Civil Service Commission announces the following named open competitive examination:

Assistant Helium Plant Operator

Applications for the position of assistant helium plant operator must be on file with the U. S. Civil Service Commission at Washington, D. C., not later than February 7, 1933.

The examination is to fill four vacancies in the United States Bureau of Mines at Amarillo, Tex., and vacancies occurring in positions requiring similar qualifications.

The entrance salary is $1680 a year, less a furlough deduction of 8½ per cent and retirement deduction of 3½ per cent.

Full information may be obtained from the Secretary of the United States Civil Service Board of Examiners at the post office or custom-house in any city, or from the United States Civil Service Commission, Washington, D. C.

SERVICES AVAILABLE

A-187. Welder desires position. Five years with the Brooklyn Eastern District Terminal. Boiler welding.

A-188. Electric and Acetylene Welder. Seventeen years' experience. Nine years as Manager of welding business and four years with Standard Welding Co. of Jersey City.

Practicability and Joint Characteristics of Arc-Welded Industrial Piping

By ROBERT DANIELS
and WARREN C. HUTCHINS

✦Paper prepared by R. Daniels and W. C. Hutchins of General Electric Company and presented by the latter at the joint meeting of the New York Section of the American Welding Society and the Petroleum and Power Division of the A. S. M. E., on December 13, 1932.

Introduction

THE practical economics of electric arc welding for industrial pipe joints has not as yet received the full recognition it deserves, particularly in view of its characteristic advantages. Unfortunately, the impression seems to exist in the minds of many that no method of welding can be applied economically to industrial piping. The primary object of this paper, therefore, is to discuss this phase of the subject in an effort to dispel this erroneous belief. To this end, we will show that labor costs and overhead are surprisingly low, that design is greatly simplified and that other important advantages accrue. The secondary object is to consider the physical characteristics of arc-welded pipe joints and show that they justify complete confidence in this method of assembly.

Piping contractors and those in charge of piping activities in industrial plants gather from trade magazines and other media that welded joints are efficient and superior to screwed joints. In spite of this information, many fail to consider the adoption of welded joints. When asked why, the frequent answers are: highly trained welders, of which there is a scarcity, are required; drafting room and assembly practices are radically different; or too much apparatus is involved. Still others, less familiar with the successful applications of welding in other fields, say that welding is not sufficiently developed to be practical. It is evident, therefore, that the proofs of the practical applicability of welding to industrial piping have not been clearly set forth; probably they have been overlooked in the zeal to emphasize the quality that can be obtained.

Securing Competent Welders

Assuming for the moment that the physical characteristics of welded pipe joints are acceptable, the first consideration is labor. How are competent welders secured? Are experienced welders available or must they be trained? If they must be trained, what financial investment is required? What wages are paid to welders? What is involved in testing and inspection? These important questions must be given earnest consideration; the extent to which welding will be used in this most important field depends upon the answers.

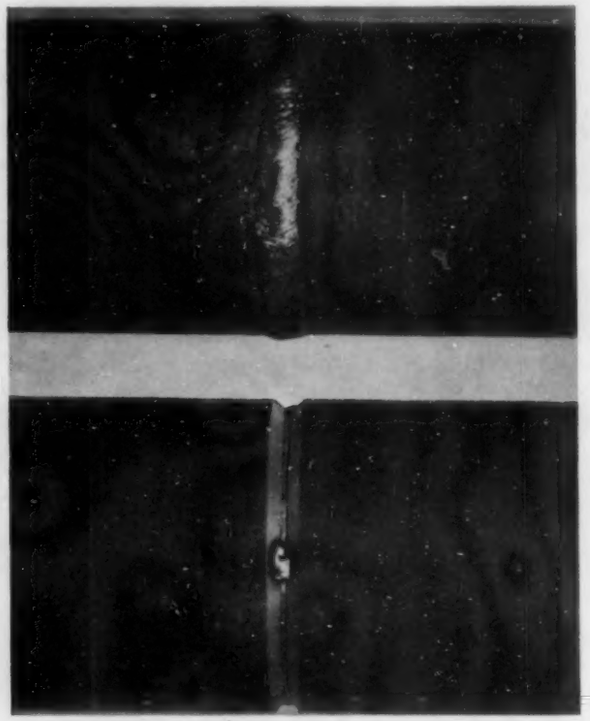


Fig. 1—Two Standard 6-In. Pipe Joints, One as Prepared for Welding and the Other in Its Completed Form after Welding

Competent hand welders are essential in the production of good quality welded pipe joints.

The time required to learn the practical fundamentals of arc welding is usually 8 weeks, depending upon the ability of the individual. Experience indicates that approximately 8 additional weeks are required to become proficient on the specific application of pipe welding. Therefore, to become qualified as a pipe welder only four months' training is necessary. Furthermore, during a portion of the later 8 weeks' period, the individual need not devote his time to non-productive practice but may be assigned work in the shop which does not require the skill of qualified welders. After gaining additional experience, he can be entrusted with jobs requiring more and more skill until he may be classed as a qualified pipe welder. He should then be able to instruct others.

Welding schools, specializing in the practical training of welders, are established throughout the country and have graduated thousands in recent years. The training is accomplished by teaching the practical fundamentals of the art. When a student welder has learned to maintain and manipulate the arc properly, he is required to weld various types of joints in all positions. The weld quality is determined by tests; the welder is not graduated until the physical characteristics of his welds meet certain requirements.

The present economic situation offers a splendid opportunity to contractors and plant managers to develop a welding personnel. Their own men can be trained at low cost or the services of qualified welders, who are unemployed, can be secured. While those welders, qualified specifically for industrial piping are relatively few, there are today a large number of experienced transmission pipe-line welders available. These men, with their experience, are suited ideally for industrial pipe welding. Men, experienced in other phases of welding, can also be readily developed into qualified pipe welders.

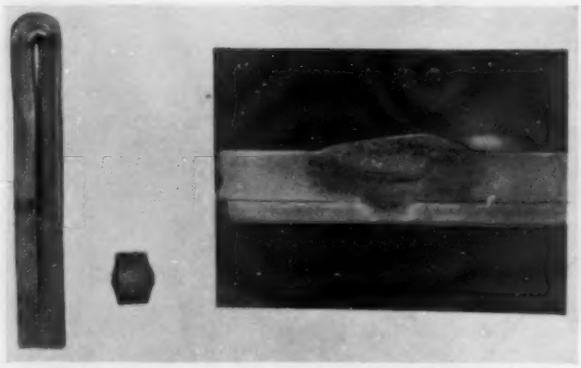


Fig. 2—(Left and Center) Coupon from Arc-Welded Pipe, Which Has Been Tested for Ductility by Free-Bending. (Right) Micrograph Mag. 2× of the Cross Section of a Pipe Weld Illustrating Grain Refinement of Each Successive Layer of Weld Metal Deposited. Three Passes Were Made

Layout of Piping

Where welding is substituted for conventional screw type joints, drafting room practice is simplified. Some standard methods will require alteration, but so obvious are these changes that the draftsman recognizes them immediately. Dimensions need only be given between center lines of fittings, and one straight line can be used to indicate the pipe. The elimination of flanges further simplifies drafting. No space consideration is given to the location of joints between pipe sections, since the outside diameter of the welded joint is essentially no more than the pipe diameter.

Shop *vs.* Field Welding

When a shop is located conveniently near the site of erection, best practice is to weld large sections of pipe in the shop. The reason is that with shop equipment, welding can be done at less cost than on the site of erection. If the joint can be rotated to permit continuous welding in the flat position, the welding speed will be practically double that for position welds. On the average, if all welds are made on the site of erection, about 50% of the joints can be rotated during welding. This percentage increases with the amount of shop welding done. Also, the joints may be rotated more easily in the shop and, if the size of the job warrants the cost of the equipment, automatic welding may be used.

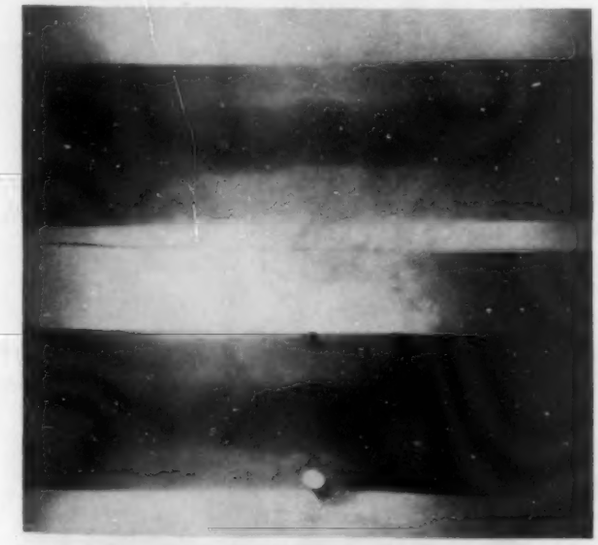


Fig. 3—X-Ray Photographs Illustrating Two Sections of a "Roll" Arc-Welded Pipe Joint

Sections of pipe, whether assembled in the shop or on the job, are laid out and measured, allowances being made for spacing at the joints, fittings where used, etc. The pipe lengths are then cut to the proper length and welded. After the section is erected in place, it is tied in with other sections of the system by position welds. The gas torch can be used to advantage for cutting the pipe. A small rotating, gas-cutting device, mounted directly on the pipe, is recommended unless the production requirements justify a larger automatic machine.

The hoisting of large sections of welded piping does not involve the possibility of damage to the joint, as in the case of screwed and bolted joints. Arc-welded joints are stronger than the pipe itself and are very ductile.

Preparation and Welding of Pipe Joints

The preparation of butt joints for welding industrial piping necessitates the beveling of the pipe ends to an angle ranging from 30 to 45 deg. The end of a pipe is not beveled to a sharp edge but a section about $^1/_{16}$ in. thick is left on its inner edge. The total elimination of the shoulder by beveling is desirable from a welding viewpoint if fusion rings (usually called chill rings) are used. This, however, is not practical where pipe is shipped from the mills, due to the damage which the feather edges will receive in handling. A feather edge can be secured on the job at the same time the pipe is being cut to proper length with a cutting torch.

Conditions under Which 6-In. Pipe Joints Were Butt Welded

Joint No.	Roll or Position	Chill Ring	Electrode Diameter, In.	No. of Passes	Tensile Strength Reduced Section A.S.M.E.	Tensile Strength 2 In. Radius	Ductility Free Bend, %
1	Roll	No	$^3/_{16}$	3	58,900	61,200	51.8
2	Roll	Yes	$^1/_4$	2	59,700	63,700	49.9
3	Roll	Yes	$^3/_{16}$	2	59,400	64,300	53.0
4	Roll	Yes	$^3/_{16}$	3	57,900	64,500	58.5
5	Position	Yes	$^5/_{32}$	2	62,200	61,800	46.4

Electrode consumption per joint approximately 0.8 lb.

Fig. 4

Fusion or chill rings or reinforcing liners have not met with general acceptance, possibly due to the slight restriction of pipe area of each joint. This restriction, however, in a 14-in. pipe is only 4% of the pipe area.

In preparation for welding, the pipes are usually separated at the joints, a distance equal to the diameter of the electrode to be used. When a fusion ring is employed and the joint properly spaced, the welder can obtain 100% penetration of the joint even at the inner edges of the pipe by fusing into the ring when making the first pass. When the fusion ring is not used, the welder should secure complete penetration to the best of his ability, yet he cannot afford to burn completely through. Burning through generally produces obstructions or "icicles" on the inside of the pipe. Moreover, if a large opening has been made in burning through, it will be difficult to refill and generally an inferior weld will result.

Perhaps the disadvantages of fusion rings have been over-emphasized, particularly in view of the advantages gained by their use, such as uniformly complete penetration, absence of icicles, higher welding speeds and other factors which generally make them worthy of adoption.

In G.E. factories fusion rings are specified for butt

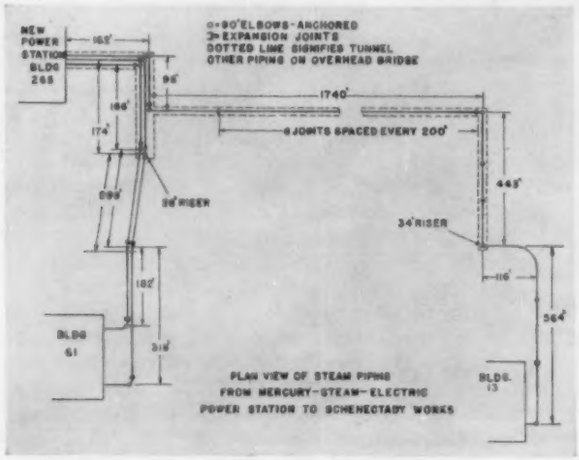


Fig. 5

joints when the pipe is greater than 4 in. in diameter. Butt welds are not made on pipe less than 2 in. in diameter; a sleeve is placed over the joint and a full fillet weld made at each end. Butt joints between 2 in. and 4 in. are welded without 100% penetration, but this is compensated for by excessive reinforcing of the weld.

The average fusion ring is about $^1/_4$ in. thick by 2 in. wide. Standard types are available on the market with impressed bosses around the center of the outer surface, which serve the purpose of spacing the joints. The circumference of the rings is usually cut in one place to permit fitting into the pipe.

If pipe joints are securely tack welded, no warping or deformation will result when welded. It is recommended, therefore, that numerous light tack welds be made in the assembly of joints instead of a few heavy tack welds.

Inspection of Welds

The practice of testing and inspecting welds is recommended, particularly if the piping is for high pressure or high temperature service. Recently the General Electric Company installed nearly a mile of 14 in. piping for steam service at 400 lb. pressure and 750° F. The pipe wall thickness is $^1/_2$ in. Before a welder was permitted to work on the line, he had to pass a rigid qualification test in view of the severe service the line was to encounter. In addition to this, each joint was carefully inspected while it was being welded and after it had been completed. The inspector was given the authority to cut welded joints from the line for testing purposes whenever he considered it advisable. With experience an inspector can predict, surprisingly accurately, the weld quality by observing the welder at work and by the steadiness of the arc voltage.

For low pressure applications, inspection may be supplanted by hydrostatic testing of the completed system or sections thereof, which will reveal poor workmanship. Where sections of piping are being welded in the shop, the foreman can very easily observe the proficiency of the welders. This permits the selection of the most reliable individuals for field work.

Cost

1. Welding Equipment.—The cost of arc-welding equipment, although an important item, cannot be classified as making the process impractical. Complete equipment for an operator can be secured for much less than $1000 if electric power is available, and for slightly more if a gasoline engine-driven set is used. If several operators are to assemble sections of piping in the shop, their welding equipment cost is reduced considerably, since one large generator can be used to supply power to a number of welders. The maintenance and operating cost of welding machines need little consideration.

2. Power.—The total electrical energy required in welding a 6-in. standard butt joint, including losses in the welding set and energy consumed during idling time, is approximately 1.15 kwh.

3. Electrodes.—The cost of welding electrodes is small. For example, the weight of electrode required in making a 6-in. joint is about 0.8 lb. Assuming a price of 12¢ per pound, the electrode cost for this joint is 9.6¢.

4. Labor.—Arc welders are not paid an exceedingly high wage in that the complete training of a man to become a qualified pipe welder averages about four months.

Advantages of Welded Pipe Joints

1. Strength.—The unit tensile strength of arc-welded pipe joints is in excess of 60,000 lb./sq. in. and there is no reduction in wall thickness, thus retaining the full strength of the pipe. The standard threading on a pipe reduces its effective wall thickness about 30%, correspondingly reducing the pipe strength.

2. Ductility.—The ductility of an arc-welded pipe joint, when tested by the free-bend method, exceeds 40% and permits bending without consideration of the joint location. In pipe-lines made up with screwed or bolted fittings, bends are carefully avoided at the joints.

3. Resistance to Corrosion.—It has been proved by test that the resistance to corrosion of an arc-welded pipe joint is superior to that of the pipe itself. Weld metal deposits made on A. S. M. E. S-1 steel boiler plate with our heavily coated electrodes have shown greater resistance to hydrochloric and sulphuric acid attack than the boiler plate. Threads are readily at-

Fig. 6—Arc-Welded 14-In. Pipe-Line for 400 Lb./Sq. In., 750 deg. F. Steam Service and Return Line Emerging from Underground Tunnel to Overhead Bridge to Building No. 13

tacked by corrosive elements and gaskets deteriorate with age.

4. Weight.—The weight is reduced by the elimination of castings, bolts, nuts, etc.

5. Space.—Welded joints eliminate the space required for flanges and other fittings.

6. Insulation.—Welding reduces the quantity of insulating material and labor required, since there are no appreciable irregularities of the pipe surface.

7. Inventory.—The large stock of fittings required for screw type joints is reduced to a very few standard fittings. Even these are not absolutely essential and, in an emergency, joints can be fabricated.

8. Flexibility.—Standard fittings usually include ells of a few different angles such as 90° and 45°. When welding is used, fabricated angles or turns can be made for any desired number of degrees.

9. Costs.—Decided cost savings can be made on pipe above 2 and 3 in. in diameter.

10. Speed.—Experience indicates that the time required in arc welding a joint is less than for threading and assembling a screw type joint.

11. Repairs.—Large pipes can be repaired on the site with greater rapidity and at less expense.

12. Economy.—Possible saving in cost of pipe is accomplished due to elimination of threading.

13. Appearance.—The elimination of clumsy fittings results in a continuous, smooth and pleasing appearance.

14. Efficiency.—Smoothness of interior and uniformity of bends reduces losses due to friction and eddies that cannot be avoided in lines connected by threaded fittings.

Tests of Welded Pipe Joints

Endeavoring to secure accurate data on the characteristics of arc-welded pipe joints, early this year we conducted a series of tests. It was necessary to establish certain limitations for the investigation. Standard 6 in. diameter pipe was decided upon. Its average physical properties were as follows:

Ultimate tensile strength	60,800 lb./sq. in.
Yield point	42,700 lb./sq. in.
Elongation in 2 in.	48%

In making these experiments, no attempt was made to test welded fittings. The tests were confined generally to butt joints and bell and spigot joints between straight lengths of pipe. This latter type of joint, while never used on industrial piping, involves a full fillet weld, sometimes required with certain fittings. Tensile strength tests on the welded bell and spigot joints invariably resulted in fractures outside of the welds, indicating that this type of joint can withstand the most severe service. A full fillet weld contains more weld metal than a comparable butt weld, therefore the bell and spigot joint is not highly recommended, due to its higher cost compared to that of butt joints.

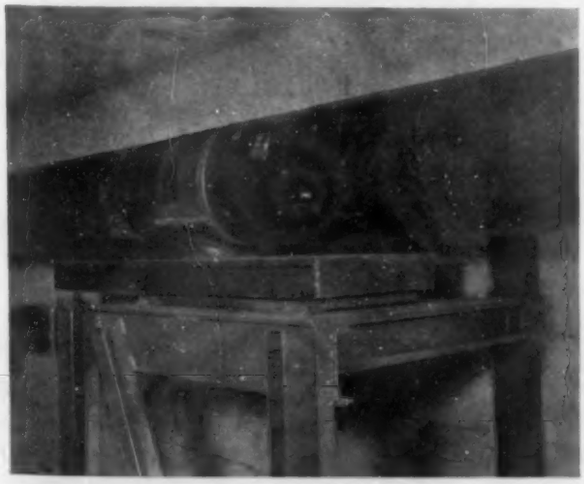


Fig. 7—Arc-Welded Butt Joint and Multiple Collar Pipe Support for 14 In. Diameter Steam Pipe-Line

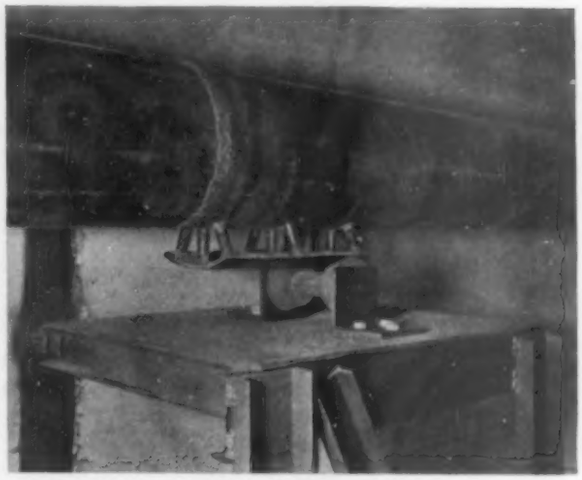


Fig. 8—Butt Joint and Ordinary Roller Support for Steam Pipe-Line

Heavily coated electrodes are now standard in all kinds of arc-welded piping and were used in conducting these tests. It will be evidenced by the data given that heavily coated electrodes have decided advantages over bare or lightly coated electrodes from both quality and production standpoint.

The butt joints were welded with and without fusion rings. Figure 1 shows a 6-in. pipe butt joint tack welded, then completed.

The number of passes or weld metal layers were given consideration. It is common knowledge that each successive layer of weld metal deposited, heat treats and thus partially refines the metal previously deposited. This can be better appreciated by referring to the macrograph of Fig. 2, which shows a cross section of a welded pipe joint made in three passes. Note that the first layer of metal has a fine grain structure, the second layer is less fine and the third layer is relatively coarse grained. Thus, if two passes are made instead of three, there will be a larger quantity of weld metal which has not been heat treated by subsequent passes. As will be indicated by the test data, however, the extra pass on 6-in. pipe does not increase the physical properties sufficiently to warrant three passes instead of two, particularly when time and expense are considered. In Fig. 3 is seen an X-ray of a roll joint. Note the excellent quality of weld metal.

The welding current, arc volts, polarity, joint spacing and welding speeds were consistent with best welding conditions. All welded joints were closely inspected during and after completion of the welding to make sure that at least 20% crown was maintained and that no undercutting occurred. The welder removed the slag coating from the weld metal after each layer was deposited. The width of the finished weld ranged from $2^1/_2$ to 3 times the wall thickness of the pipe.

Butt joints were welded under five different conditions, two duplicate samples being made for each. The five conditions are as shown in Fig. 4.

Every possible effort was exerted to obtain average values over such a range as to give reliable results. It appears that this was accomplished to a fair degree of accuracy. Coupons from each pipe were tested for:

1. Tensile strength in accordance with Standard A. S. M. E. Boiler Code reduced-section tension test, and special 2-in. radius reduced-section tension test.
2. Ductility by free-bend test. (A. S. M. E. Boiler Code.)
3. Nick-break test. (A. S. M. E. Boiler Code.)

Five coupons from each of two duplicate joints were tested for each of the above requirements. In the case of the position weld, six coupons were tested for each requirement, two each from the bottom, sides and top. Coupons which were to receive the same test were cut from the pipe at points not adjacent to each other.

All coupons were prepared and tested in strict conformity with the A. S. M. E. Boiler Code with the exception of the special 2-in. radius reduced-section coupons. These were prepared by milling a 2-in. radius section, $^1/_4$ in. deep, across each edge of the specimen at the weld. The width of the specimens at the reduced section was $1^1/_2$ in.; the weld metal crown, together with the chill ring, was machined flush with the plate. When prepared in this manner, fracture should always occur in the weld, unless it is *much* stronger than the parent metal.

Attention is called to the fact that the majority of the A. S. M. E. reduced-section specimens failed outside of the weld metal. Although a few of the special 2-in. radius specimens failed in the parent metal, they may be considered as more representative of the weld metal strength.

Detailed test results from which the average values shown were secured may be obtained in printed form from our Company, Bulletin GET-512.

To obtain additional comparable data, the welder was instructed to produce an all-weld metal block from which were prepared A. S. M. E. standard tensile, specific gravity and impact specimens. The first two types of specimens were prepared and tested in accordance with the A. S. M. E. Boiler Code and impact tests were made by the Charpy method. The results for six different specimens were as follows:

All-Weld Metal Tension Tests

Specimen	No. 1	No. 4
Tensile strength—lb./sq. in.	65,100	64,900
Yield point	46,000	47,700
Elastic limit	45,000	47,000
Reduction of area	34.2%	34.8%
Elongation in 2 in.	23.5%	23.5%

Specific Gravity Tests Showed

Specimen No. 2	7.86
Specimen No. 3	7.86

Charpy Tests—Impact

Specimen No. 5	35.3 ft.lb.
Specimen No. 6	36.9 ft.lb.

To further ascertain the quality of weld metal secured in these tests, a number of the joints were radiographed. The X-ray prints indicated that roll welds conformed with the A. S. M. E. Boiler Code for Class I requirements and the position welds conformed with the A. S. M. E. Boiler Code for Class II requirements.

From this series of tests, the following conclusions were drawn:

1. The physical properties of arc-welded pipe joints are superior to pipe joints made by other methods, for the following reasons:
   Average tensile strength—above 60,000 lb./sq. in.
   Average ductility by free-bend test—45%
   Freedom from slag inclusions and porosity come well within the A. S. M. E. Boiler Code requirements for Class II Pressure Vessels.
2. Heavily coated electrodes are to be preferred over bare or lightly coated electrodes because of the quality of welds produced.
3. Two distinct types of heavily coated electrodes should be used if maximum economy is to be obtained; one for roll welds and the other for position welds.
4. The straight butt joint with chill ring is to be preferred over other types.
5. The fusion ring or reinforcing liner (often called chill ring) is essential to the well-made pipe joint.

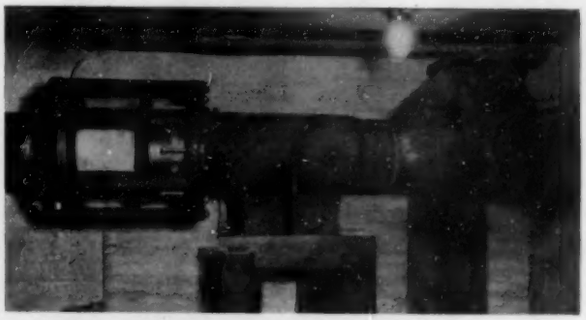


Fig. 9—Arc-Welded Slip Expansion Joint and Elbow in 14-In. Diameter Steam Pipe-Line

While the difference in tensile strength for roll welds made with and without fusion rings under duplicate conditions is small (64,500 compared with 61,200 lb./sq. in.) it is probable that welders would more readily succeed in continually making such quality welds with fusion rings on a production basis.

6. Two passes instead of three are to be preferred on 6-in. pipe joints due to the saving in time and expense. The average tensile strength value for roll welds made in two passes is 64,000 as compared to 64,500 lb./sq. in. for three passes, a negligible difference.
7. Position welded joints made with fusion rings are closely comparable in strength to roll welds made under similar conditions, e.g., 61,800 compared with 63,700 lb./sq. in.
8. The ductility of all types of welded pipe joints made with the electric arc and heavily coated electrodes approaches that for the pipe material more closely than does any other type of pipe joint.
9. The density of the weld metal is comparable with that of the pipe material and the resistance to impact and corrosion is greater.

Welded Industrial Piping Installations

In line with modernization, General Electric is vigorously pushing the erection of its 20,000-kw. mercury-steam-electric power station at Schenectady, (Fig.11). The final smoke-stack was completed recently and the present prospect is that this $4,000,000 plant will be ready for operation next spring.

From an engineering view-point, the power plant is, in several respects, astounding. It will be the first

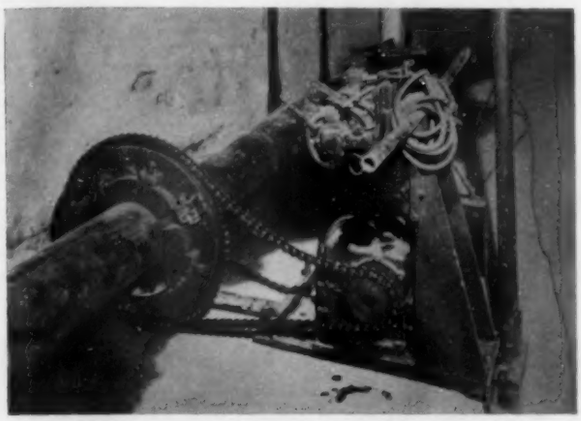


Fig. 10—Motor-Driven Pipe Rotating Device, Built by Schenectady Works and Used in Making Roll Welds on 14-In. and 8-In. Steam Pipe-Lines

outdoor steam-electric generating plant ever built, and it also represents the *first* instance of coordinating public utility and industrial power needs, building immediately into the system the use of a mercury boiler and turbine. The electrical output of the power plant will be fed into the commercial system of the New York Power & Light Company, while the steam output will be used in the Schenectady Works of our Company for process and heating purposes.

The transmission of this steam will be through three 14 in. diameter pipe-lines with $^1/_2$ in. wall thickness, and will handle 500,000 lb. of steam per hour from the power station to the works. A plan view of the piping layout, totaling 4800 feet of 14-in. pipe and more than 3000 ft. of 8- and 10-in. piping, is outlined in Fig. 5. The 14-in. lines are designed for 400 lb./sq. in. 750° F. steam service. One of them will be immediately used for steam of this pressure and temperature upon completion of the power station. The others will for the present be in service for 225 lb./sq. in., 150° F. super-heated steam. Condensate will be returned through the standard pipe-lines, one 8 in. diameter and the other 10 in. diameter.

The major portion of the pipe-lines are in tunnels, the remainder being supported from overhead bridges, also of arc-welded construction as shown in Fig. 6. The steam piping is covered with $4^1/_2$ in. of insulation and the condensate return lines with $1^1/_2$ in.

Slip expansion joints with flangeless connections of all arc-welded construction are spaced every 200 ft. in the steam line, and every 300 ft. in the condensate return lines. Guide rolls, of the type shown in Fig. 7, were fabricated by us and are located near the expansion joints to prevent side swaying of the pipe. Spindle rolls, Fig. 8, support the line at points between guide rolls. The majority of turns are made with standard elbows, having arc-welded anchoring supports as shown in Fig. 9, which also shows an expansion joint.

Two variable speed, motor-driven pipe-rotating devices were made to facilitate the continuous welding roll joints. One is shown in an operating position in Fig. 10.

The practice adopted for installation of the tunnel piping was, briefly, as follows: individual 35-ft. sections of pipe were mounted upon temporary rolling devices for rotating the pipe. After fusion rings had been located at the joints and the proper spacing obtained, five such pipe sections and the sliding end of an expansion valve were securely tack-welded together. The entire unit was then rotated by the motor-driven rotating device at welding speed, while operators welded the joints. After the completion of roll welds, the expansion rolls previously mentioned were placed beneath the pipe, and position welds made between sections.

The steam piping is completed. After witnessing the numerous tests made during erection, the responsible engineers were so confident of the welded joints that all the insulation was put on the pipes before steam was turned on. Steam pressure has been on the line for several days and not a single leak has been detected.

To further exemplify the faith General Electric has in welded industrial piping, we cite another outstanding installation. In their new filament building of the Cleveland Wire Works, costing in excess of $1,000,000, approximately 10,000 arc-welded pipe joints connect miles of pipe. These pipes range from 1 in. up to 12 in. in diameter and distribute heating and process steam, water and various gases which are required in the manufacture of electric incandescent lamps.

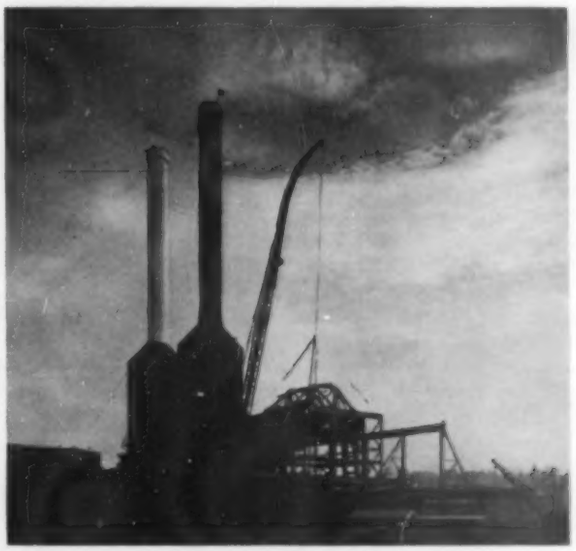


Fig. 11—Flag Unfurled Atop Final (Second) Smoke-Stack on G.E. Outdoor Mercury-Steam-Electric Power Station, Building 265, G.E. Schenectady Works

Welded Rail Joint Report

A book of more than three hundred and fifty pages summarizing a ten-year program of investigations on a great many phases of welding. Price $1.00.

American Welding Society

Design Your Welded Piping

By F. S. G. WILLIAMS

✦Paper presented at Joint Meeting of the New York Section, American Welding Society and the Petroleum and Power Division, American Society of Mechanical Engineers, on December 13, 1932, by F. S. G. Williams of the Taylor Forge and Pipe Works.

WELDING, as a method of joining pipes, has spread very rapidly in the past few years, and I regret to say it, but the fact remains that it has attained its present position in spite of itself.

There are too many specifications that read about like this: "The contractor may, if he so desires, weld all joints on sizes 2 in. and larger, etc.." I hope to present certain facts this evening that will demonstrate to the engineers the need for adequately designing their piping for welding. Obviously, I cannot cover in twenty minutes the whole subject of welding, and I shall, therefore, pass over the welding process, welding rod, test procedure, etc., and focus attention on two matters that have been frequently overlooked.

There are two precautions which will do more good than any others at the present time to give increased confidence in welding. Insist that only qualified welders work on the job and specify the use of properly designed seamless fittings. Qualification of the welders eliminates the poor workman and the use of seamless fittings guarantees the quality of the materials used and reduces the welding to a simple system of circumferential joints, the technique of which is well established. Past experience has demonstrated the complete reliability of the open single vee butt-weld when made by qualified welders.

Many engineers are not yet sufficiently familiar with welding to realize the absolute necessity for protecting themselves by these two methods, both of which serve to reduce the application of welding to its simplest forms and relegate the human factor to the background. Also, there are many erroneous ideas that have sprung up and I am going to present certain engineering facts and data to show the correct design.

Before manufactured fittings appeared on the market, the welding torch was the only tool and the cut-fit-patch method was the only one available. The miter elbow and tee was the best there was, but that has all changed. There has been a rapid and highly competitive development of fittings to give perfect flow conditions. These fittings are now available from stock in nearly every distributing center around the country, and the use of the hand-made job is no longer justified in view of the better construction now available.

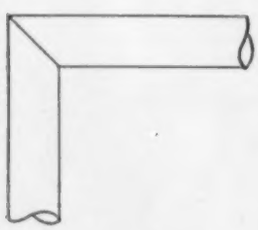


Fig. 1
Meter Elbow

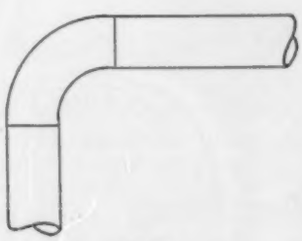
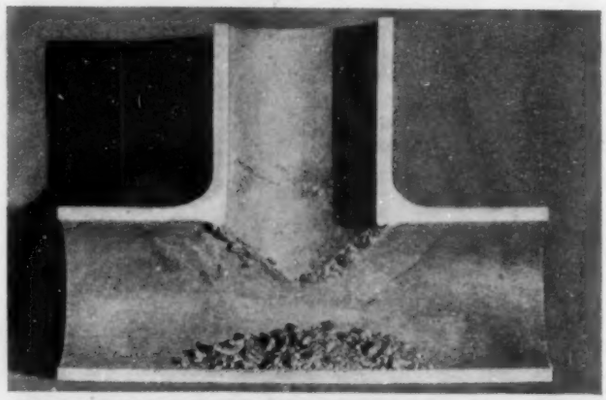


Fig. 2
Seamless Elbow

Fig 3—Branch Welded into a Main



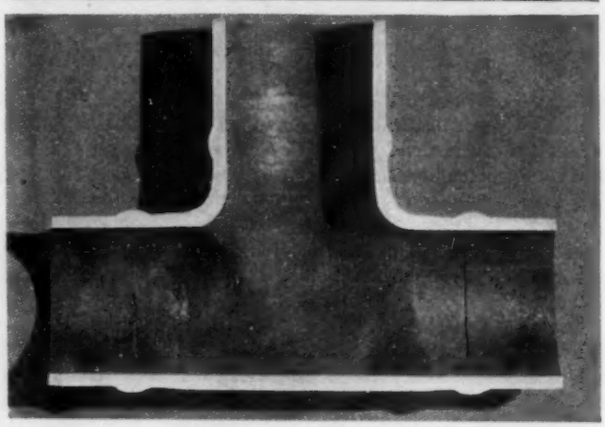


Fig. 4—Seamless Welding Tee

To illustrate graphically the differences between the two grades of construction, let us see what might be used with no specification and what could be had if the contractor were told what was wanted. The miter elbow in Fig. 1 would be the most likely result where no specifications were written, whereas it would have been very easy for the engineer to get the good construction illustrated by the seamless elbow in Fig. 2, had he taken the precaution to specify what would be required.

In Fig. 3 you have a clear-cut sample of what actually happens when a branch is welded into a main. Note the slag that is in the pipe. It is often hoped that this slag is removed, but there is no way of insuring that it is. This is an example of a good piece of work, but note the square corner which cannot be avoided, and picture for yourself the possibility of restricting the flow of the system if the branch line projected ever so slightly into the main pipe.

In Fig. 4 is shown clearly what could have been obtained if seamless welding tees had been specified. No holes have been cut in the pipe. There are no jagged edges. The flow is properly stream-lined to make the least possible resistance, and note also that the areas of stress concentration around the throat or junction between the branch and main run have been properly reinforced by additional metal to adequately handle the extra stresses which exist in these areas.

The sad part of the situation is that there are some people who even today believe that the old cut-fit-patch method gives as good results as the job where properly designed fittings have been employed. A very interesting example of this situation came to light recently in a

Fig. 5
FLOW TEST ASSEMBLIES.

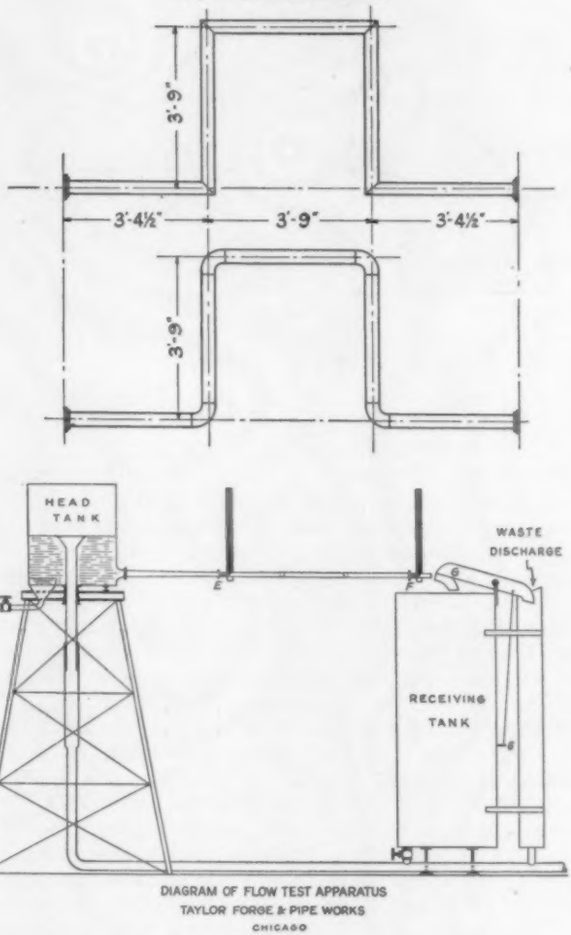


Fig. 6

certain district. An enterprising contractor, who had a machine for cutting miters, set out to get work and, on the strength of some rain barrel tests, convinced the engineers in that area that the miter elbows gave as good flow as seamless manufactured elbows.

Now let us examine the real facts. A piping system never consists of one elbow and a short piece of pipe It is usually a combination of many elbows, some of them at frequent intervals and some of them widely spaced, and it is the cumulative effect of these elbows that is the real test of frictional resistance. The Taylor Forge & Pipe Works recently conducted a series of flow tests, taking great care to get a true picture of the exact amount of head lost through similar assemblies made up with seamless elbows, with miter elbows and standard screwed elbows. Figure 5 shows the detail of two assemblies which were tested. These were identical in dimension and were made from 3-in. pipe and elbows. Figure 6 shows a schematic arrangement of the apparatus used in the test.

A head tank was provided as a source of constant head for the water flowing through the piping system. Water entered in inlet valve flowing upward through baffles and overflowing into conical weir. The level of the water in the tank was measured by means of a water column. The piping assembly between joints "*E*" and "*F*" was leveled with a spirit level. Flanges "*E*" and "*F*" contained a $^1/_4$-in. hole to which tubing was attached leading to differential water column. The tap connections were on the center line of the pipe as viewed in the sketch. The holes were carefully cleaned to remove burrs and projections where the hole entered the pipe. The receiving tank was calibrated by pouring a definitely weighed quantity of water into it before the test was commenced. The water was measured during the test by noting the level on the water column at the beginning and end of the run. Point "*G*" on the figure is a quick acting deflector valve arranged so that with lever arm "*G*" pulled down, water from the test apparatus is discharged into the measuring tank, while with the lever "*G*" pushed up, the complete flow is delivered to the waste discharge pipe which enters drain piping which discharged into a sump.

It was our object to control flow conditions in such a manner that the velocities passing through the piping assemblies would be kept constant for each test run. A set of runs was made on the Taylor elbow assembly varying the head in such a manner for each different run so that the velocity would be increased by increments of about 1 ft. per second. The miter piping system was then connected and the head was controlled so as to give the same quantity of water in tank "*B*" per unit time as was obtained on the runs on the Taylor elbow piping. This was repeated with screwed ells and a straight run of pipe having a length equal to the center line length of the assemblies tested.

The procedure in running the tests was first to adjust the telescopic head so that water just flowed over the weir. After about five minutes, in order to allow the flow to reach equilibrium conditions, an observer, stationed on the floor level by the receiving tank, read a small quantity of water which was always allowed to remain in it, and then flipped the deflector valve "*G*," which had been discharging to overflow, so that water from the piping system entered the measuring tank. The time during which water was entering the tank was measured with a stop watch and recorded on the data sheets. During the time water was flowing into the measuring tank readings of the water columns were taken. After the end of the test run and when the water had come to rest in the receiving tank, the water level in this tank was recorded. The difference in water level from beginning to end of the test was reduced to velocity of water in the piping system from the calibration chart. Each test run was repeated four times and values were averaged. It was noted throughout the run that there was very little fluctuation in the water columns.

Great care was exercised in making up the flange joints

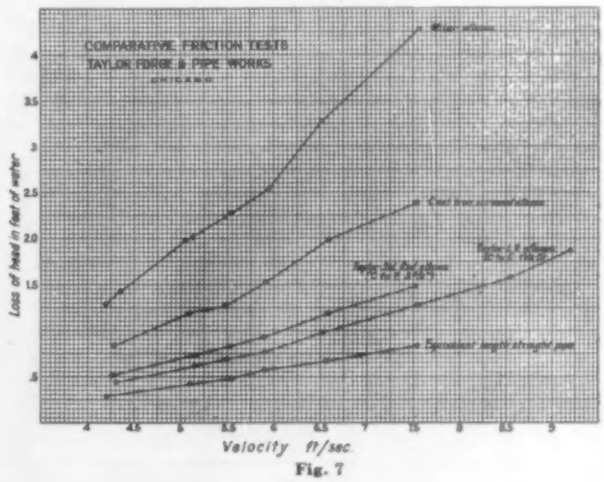


Fig. 7

"*E*" and "*F*" in the test piping. Rubber gaskets were cemented to one of the flanges and cut so that there was no projection into the pipe. The piping was lined up perfectly so as not to create any disturbances. Air was expelled from all of the rubber tubing connecting the various water columns by disconnecting the tubing from the water column and allowing the water to flow freely for several minutes.

A test was also made of the actual loss of head in a length of straight pipe equal to the total center line length of the various assemblies, all of which were the same.

Referring to Fig. 7, Curve No. 1 shows the actual loss in head in the straight pipe. Curves Nos. 2 and 3 show the loss of head in the seamless elbow assembly and Curve No. 4 represents the loss in the screwed fitting assembly, while Curve No. 5 is for the miter weld assembly.

The vertical distances between Curve No. 1 and any of the other curves give the actual frictional resistance due to four elbows. It is surprising to note the vast difference in head loss between the types of construction. It is obvious from data of this kind that miter elbows are a very definite obstacle in the path of operating economy.

A study of this type of data will show that it is possible to effect decided operating economies through the use of seamless welding elbows, rather than miter welds or screwed fittings. Not only is a reduction in pumping power realized, but in many cases it should be possible to buy the pump for a smaller discharge head and use a smaller motor, thus effecting a considerable reduction in first cost of equipment.

It should be the desire of every engineer to make the design such that the weld does not receive the maximum concentrated stress, as this places too much responsibility on the welder and he is blamed for the failure if it occurs. For instance, in making a single miter weld in the form of a right angle turn in a pipe, we can assume that the weld is perfect, and even 10 per cent stronger than the solid metal. Still, with the most perfect weld, failure cannot be prevented from occurring at the point of the crotch, which is at the weld, if the stresses become too great as a result of the weaving action concentrated at this weld from the very nature of piping design.

Hence, it is good engineering to use a design and products that take care of the stresses and eliminate their concentration at the weld. The advantage of the use of the seamless elbow is that, while the stress remains at the crotch or middle of the elbow, it is away from the weld and the breathing is handled by the seamless metal which distributes the stress over a large area and is not concentrated on individual lines or points.

In drawing specifications for elbows the engineer should bear in mind these fundamental facts. First, that the stresses due to bursting pressure are very definitely concentrated at the throat or inner radius of an elbow. Second, that the mechanical stresses imposed upon a piping system, due to expansion and contraction, are concentrated upon the elbows, and this movement in the piping causes a breathing action in the elbow.

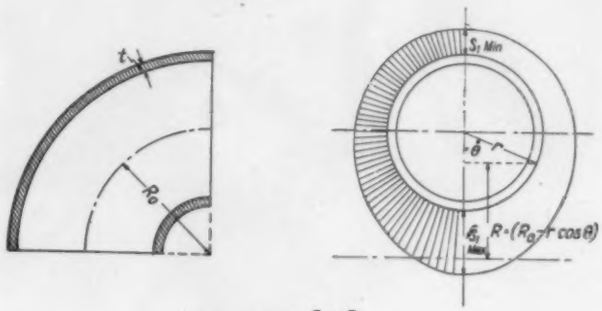
Formula for Bursting Stress of a Tube of Circular Cross Section Whose Center Line Is an Arc of a Circle

$$S_1 = \frac{pr}{2t}\,\frac{R + R_o}{R}$$

where S_1 = bursting stress, lb. per sq. inch
p = internal pressure, lb. per sq. inch
t = thickness of pipe or fitting wall, inches
r = inside radius of fitting or pipe wall, or outside radius if Barlow's formula is desired, inches
R_o = radius of fitting center line, inches
R = $(R_o - r\cos\theta)$ = radius of any point in fitting cross section

Fig. 8

DIAGRAM OF BURSTING STRESSES IN AN ELBOW OF UNIFORM WALL THICKNESS



$$S_1 = \frac{pr}{2t}\,\frac{R + R_o}{R}$$

Fig. 9

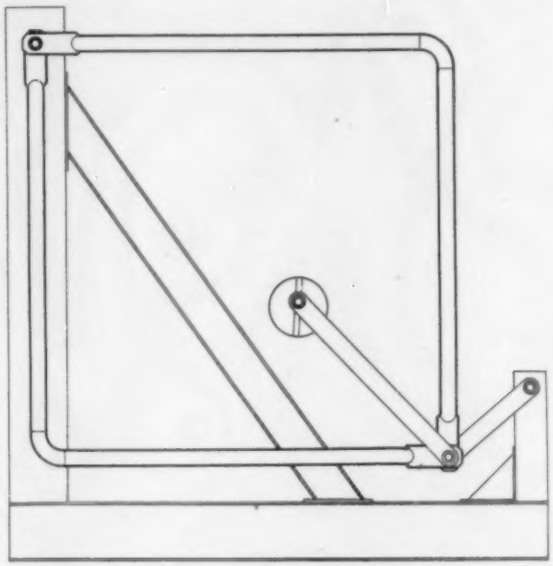
Figure 9 illustrates graphically the stresses at various points around the surface of an elbow, having uniform wall thickness. The stresses have been plotted as extensions of the radius and the length of each line indicates the relative stress at that point.

This formula verifies the conclusion that the maximum bursting stress in a 90 deg. fitting occurs in the short side of the fitting, i.e., where the distance from the axis of the fitting is $(R_o - r)$. It also permits plotting the distribution of bursting stress around any cross section of the bend. For a fitting of uniform wall thickness the maximum bursting stress, as stated, occurs at the inner side of the fitting where $R = (R_o - r)$. The bursting stress in the wall of the fitting, midway between the short and long sides, i.e., where $R = R_o$, is equal to the stress in a straight pipe, while the bursting stress in the outer side of the fitting, i.e., where $R = R_o + r$, is a minimum.

Elbows should be properly reinforced at this inside radius, not only to provide for the stresses due to internal pressure, but reinforced so that they will resist all the stresses concentrated in the elbow from expansion and contraction in the system, and distribute a portion of these into the straight pipe.

It should be frankly admitted that the elbow is a focal point of stresses. When you stop to consider the number of cycles of expansion and contraction to which an average installation is subjected in the course of its lifetime and visualize the repeated breathing action at the elbow, you will begin to appreciate the real need for specifying seamless elbows. Depend upon seamless metal to take care of this breathing and keep all welding out of these zones of stress concentration. Such argument is particularly sound today since seamless fittings are commercially available in all parts of the country.

We will, at a future date, give you some very interesting information in connection with the actual effect of this breathing action in a pipe-line. We have been con-



THE TORTURE RACK
Fig. 10

ducting tests with a device which is aptly called the Torture Rack. This device is illustrated in Fig. 10 and duplicates the breathing action actually encountered in service.

We have thus far been discussing stresses and it would be wrong to leave the design of elbows without calling attention to the back wall of an elbow along the outside radius. This wall should be maintained at pipe thickness and at least as heavy as the thickness of pipe used in the system.

Far too little attention has been paid in the past to the real significance of machine tool beveling on the ends of pipe and fittings preparatory to the welding operation. Figure 11 will show the ideal condition upon which the welding specification had been predicated, namely, a complete and accurate alignment around the entire circumference of the two ends to be joined. Accurate alignment and a full $^1/_{16}$-in. shoulder on the inside edge of the beveled end are prerequisites of a good weld. A true machined landing surface on a fitting or pipe is absolutely necessary as the major preventative of icicles. The only possible way of insuring this condition is to require in your specification that the welding fitting be accurately sized to a true circle and then machine tool beveled.

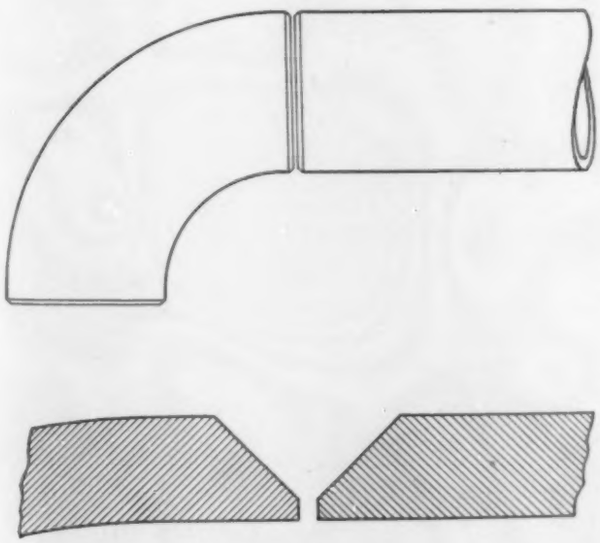


Fig. 11

The irregularities encountered without machine tool beveling require much more skill on the part of the workman to prevent icicles from forming. It means slower and more careful work with resulting higher costs if good workmanship is to be maintained, or if inspection is lax it means relatively poor welding with chances for many icicles.

Machine tool beveling gives a true, accurate surface and controls the accuracy and speed with which good welding can be done. The machine tool, once it is set, bevels in a true circle and the bevels are precise. The man in the field will be the first one to learn that machine tool beveling reduces the amount of time required to properly align the fittings preparatory to welding and that fittings and pipe with machine tool beveled ends can be welded more rapidly than those not finished in this manner.

It is earnestly hoped that the engineering profession will realize that welding has now reached the stage where it can be safely specified and that they can be sure of obtaining good results if they themselves will take the time and trouble to design the job for welding. Use only qualified welders, specify that only seamless welding fittings be used, and the piping system will have proper design and better flow conditions. The welding on the job will have been reduced to its very simplest terms and the human element relegated into the background.

Design your welded piping system to take advantage of the developments of the past few years. The engineer who has previously hesitated to specify welding can now do so with absolute assurance that he will get a good job if he takes the time to design the system for welding and write adequate specifications.

Obtain the advantages and economies of the welded system, but take care to insure the finished results by designing the job. Qualify the welders and specify seamless fittings.

Welding Standardization and Promotion in the Piping Industry

By S. LEWIS LAND

✦Paper presented at Joint Meeting, New York Section, American Welding Society and Petroleum and Power Divisions, American Society of Mechanical Engineers, Dec. 13, 1932, by S. Lewis Land, Educational Director, Heating and Piping Contractors National Association.

IT IS fitting that your two professional societies with so many interests in common in the development of welding should meet in this joint session to discuss those interests and to make plans for a more effective development of programs of action which are of mutual interest to both groups. I am glad to bring to you the greetings of our national trade association which likewise has some interests in common with yours and to tell you something of its welding program.

The welding activity of the Heating and Piping Contractors National Association is still in its youth, but we believe we have begun to realize very substantial returns on the program of our Committee on Welding, the activities of which are due in large part to the vision and foresight of its Chairman, John H. Zink.

Under the guidance and aggressive direction of our Committee on Welding we have developed a program designed to assist our members in the application of welding to pipe installation, three phases of which I shall attempt to briefly present to you.

Pipe Welding Specifications

Our "Specifications and Standards Covering the Welding of Steel and Wrought Iron Pipe" have had a ready acceptance on the part of architects, engineers, governmental departments and others. These specifications cover the requirements for fusion welding in both the oxyacetylene and electric arc processes of all steel and wrought iron pipe, both standard and extra heavy weight, for steam and process piping operating at pressures not exceeding 250 lb. (gage pressure) and at temperatures not exceeding 406 deg. Fahr. The purpose of these specifications is to regulate and standardize the application of fusion welding in the piping industry and to provide economical and uniform methods of weld tests. The Committee has in process of preparation at this time a Code for Pressure Piping for pressures above 250 lb.

To meet the demand of architects and heating and ventilating engineers for specifications covering the welding of pipe to be incorporated in any general specification of heating and other piping, a short form specification has been provided which can be added to or incorporated in any general specification for pipe installation.

These specifications were prepared by our Committee on Welding, approved by our Committee on Standards and adopted by our National Association. They have been incorporated in specifications covering piping installations in several buildings of the United States Bureau of Standards as well as other government buildings, in the specifications of State engineers covering the installation of piping in State buildings as well as in the specifications of architects and engineers for private buildings. Here, for instance, is an excerpt taken from a specification covering the installation of piping in one of the government buildings in Washington, D. C.

"The workmanship, qualification of welders, weld tests, etc., shall conform with the 'Specifications and Standards Covering the Welding of Steel and Wrought Iron Pipe' of the Heating and Piping Contractors National Association."

Standard Manual on Pipe Welding

A second phase of the program of our Association which I want to point out to you is the preparation and publication of our "Standard Manual on Pipe Welding." In this work we had the very active cooperation of a number of your own members. On our Editorial Committee, for instance, were three members of the AMERICAN WELDING SOCIETY, T. W. Greene, F. E. Rogers and A. G. Wikoff.

This work was prepared to serve as a guide for the contractor, as a handbook for the journeyman fitter, as a reference volume for the architect and heating and ventilating engineer and as basic text material for training programs in pipe welding. The response which we have had during the short time of its use indicates that it is filling a real need. Aside from its use as a basic text in a number of vocational schools offering courses in pipe welding, it it used by architects and heating and ventilating engineers, by contractors and their mechanics, and is found in public libraries in 36 of the 48 States and 11 foreign countries.

Training Programs

The last phase of our service which I want to discuss briefly with you is that of the promotion of training programs for journeymen steamfitters. There are many phases of this whole problem, several of which I discussed in some detail at the annual meeting of the International Acetylene Association, held recently in Philadelphia, which was attended by a number of those who are present here. Consequently, I shall not enter now into a detailed discussion of this phase of our work and the many problems involved in the organization and administration of these training programs. Through the cooperation of our local associations, local unions of steamfitters and local vocational schools there have been set up training programs which have been operated with very effective results in several centers throughout the country, particularly in Chicago, Cincinnati, Philadelphia, Newark, Albany, Portland, Oregon, Pittsburgh and Washington, D. C.

One of the most difficult problems which we have to solve in the extension of the use of the welding process in its application to pipe installation is qualified, trained and skilled mechanics. The type of mechanic needed in our industry differs from that found in some other lines of work. Our needs require the development of welders from within the ranks of present steamfitters. A plan involving specialized mechanics who would do nothing but welding does not fit into the operating conditions found in our industry and is not economical from the standpoint of labor costs. Welders in our field must not only be artisans from the standpoint of welding, but must have the same initiative and technical ability to design, take measurements, read blue prints and the like, as is required of the steamfitter. The steamfitter who possesses these qualities can be kept steadily employed, which is an important factor in the development of his welding skill.

At the same meeting to which I have already referred, I took the liberty of suggesting that some organization in the industry should take the initiative in planning a comprehensive program for the promotion of training programs in welding which would receive the united approval and support of every trade and industry, including organized labor, in which the welding process is employed so that the greatest and most effective results might be obtained. Our Association is doing all that it can to establish welding standards with reference to the application of welding to pipe work. We do not propose, of course, to attempt to standardize, make uniform or promote training programs in other industries which may be represented through the membership of your two professional societies. We do, though, welcome the opportunity to cooperate with all the professional societies and trade associations interested in promoting uniform training programs which are to the best advantage of all groups. While I do not know what action has been taken or may be taken by that association relative to the responsibility which I indicated was theirs, I submit to you that your two professional societies have a responsibility with us as a trade association in cooperating with them in any sound plan and workable program which they may initiate which would contribute to greater uniformity in the more effective and aggressive promotion of training programs for every group.

Discussion of Papers Presented at New York Section Meeting Held on December 13, 1932

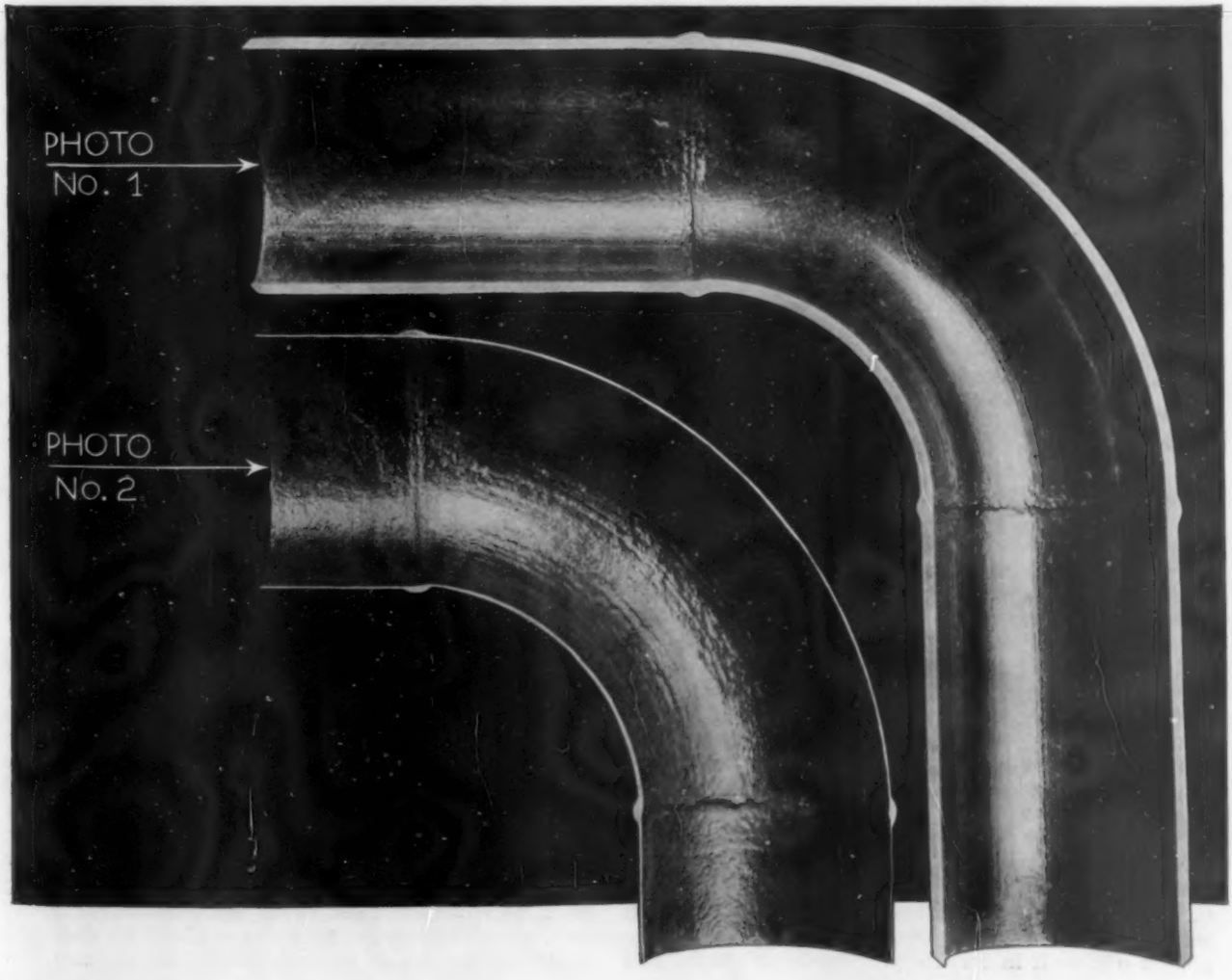
By W. P. CURLEY

✦Discussion by W. P. Curley of Tube-Turns, Incorporated, of papers read at December 13th Joint Meeting of New York Section, American Welding Society and Petroleum and Power Division of American Society of Mechanical Engineers.

MUCH has been said in the past about the ability of a welded joint to outlast the threaded one. When a southern oil refinery recently overhauled its piping system, the operating men were good enough to send us some of the piping units, and Photo No. 2 shows one of the several which we received, all strongly supporting the claims for the weld. The one shown in Photo No. 2 was a 6-in. 90° Tube-Turn with several feet of pipe beyond the weld. Photo No. 1 shows the wall thickness of this same unit at the time of installation. This comparison serves to illustrate one of the most interesting examples of excessive corrosion that we have seen for some time and is an excellent demonstration of the advantages resulting when pipe is welded.

It was installed in a crude oil vapor line between the cracking still and separating tower and had been in service for twelve months. The line operated at between 50- and 60-lb. pressure, at approximately 850° F. and at an abnormally high velocity. The crude oil contained some sulphur, but we have been unable to determine the exact content. The welds shown in Photo No. 2 were made by gas welding with high test rod.

When we received the units in our plant we cut them straight through the middle to show a cross section of the wall, and an examination disclosed that all of the pipe and Tube-Turns had worn to sheet metal thinness and that, without exception, the elbows had worn almost twice as much on the outside arc as on the inside; also, that the pipe had worn more than the elbows. To illustrate the terrific wear the system had undergone, it is well to point out that one man could lift with one hand what was left of an 8-in. 90° Tube-Turn with a 6 ft. length of pipe on each end. This one unit of the piping system originally weighed 387 lb.



All of the units which we received were well in agreement in regard to fitting and pipe wall wear due to erosion and corrosion. The 6-in. unit shown in Photo No. 2 was standard iron pipe size before installation, the original wall of pipe and Turn being 0.280 in. After one year's service the average wall thickness of the straight pipe in this unit was 0.040 in., or about 19 gage, although it is interesting to note that on some points of the pipe at one end of the elbow the wall thickness measured 0.011 in., or about 30 gage. The wall thickness of the outer wall of the Tube-Turn averaged 0.064 in., which is considerably thicker than that of the pipe. The average thickness of inner wall of the pipe measured 0.07 in., which is about as heavy as the outer wall of the Turn. The inner wall thickness readings of the Turn averaged 0.110 in., which was about twice as heavy as its outer wall and appreciably heavier than the inner wall of the pipe. It is interesting to note that the Tube-Turn even though subjected to more severe operating conditions than the pipe, due to erosion, was over twice as retarding to this influence as the straight pipe. Even though the remaining wall thickness of the unit was about $^1/_5$ or but 20% of the original wall, the entire line was tight. There were no leaks, although it so happened that for economical reasons this particular piece of piping was allowed to remain on the job longer than it should.

The weld was unquestionably the strongest part of the unit, both at the time of installation and when the unit was removed from the system. The thickness of the weld at the point of maximum reinforcement was 0.25 in. This means that the welded joint is well over 4 times as thick as the average wall thickness of the pipe itself.

Now let us see what this would have meant if the joint had been threaded rather than welded. The depth of the American standard thread on 6-in. pipe is 0.100 in. In other words, about 36% of the wall thickness is removed by threading. On this basis the remaining wall thickness from the base of the thread to the inner wall of the pipe would have been 0.180 in. if the unit had been threaded. From the wall thicknesses before and after service we can see that the corrosion and erosion rate was approximately 0.020 in. of wall metal per month. At that rate the pipe, if threaded, would have gone through completely in nine months instead of one year. However, at least some wall in the threaded joint is necessary to hold the system together. In this particular instance the wall was 0.040 in. at the time of removal. This gives us a little less than 7 months as the life of the threaded system, as against 12 months without failure in the welded unit, and this is giving the threaded unit all the breaks as it is doubtful if the threaded joint would have remained tight through that period.

Welded joints gave at least 70% more life to the system, with entire elimination of maintenance at these joints. The tight welded joint meant increased safety—a word which means more to refinery men than to any other major group engaged in industry.

The engineers at this particular refinery were so pleased at the performance record made by the welded joints and Tube-Turns that they renewed the entire system, using the identical method, except that they went to extra heavy pipe and fittings for the same operating conditions. This same refinery has been welding its pipe for more than eight years. It welds within the fire lines as well as without and welds high pressures as well as low. Operating pressures run as high as 950 lb. at 1000° F.

When the still tubes wear thin near the ends due to turbulence caused by the header boxes, the bad ends are cut off and new end pieces welded on. Then the tube is put back in service with crude at 950 lb. and 1000° F. on the inside of the tube and its outside right in the flame. There never has been a weld failure at this refinery. While it is not the largest in the world, it is one of the most progressive.

The requirements of safe practices are perhaps more necessary in the refining of petroleum than in any other major industry and in no industry has the engineering personnel been more ready to adopt modern methods for insuring safe practices.

Refining of petroleum has always involved a real hazard of fire and explosion, and, while a tremendous volume of petroleum products is manufactured with a very minimum number of disastrous consequences, this safety has been achieved only through constant effort on the part of engineers and operators in selecting none but the best of materials and methods. Pipe welding has long been accepted by most of the major refiners as lending itself toward a furtherance of the following of safe practices.

As a result of its experiences with the recently overhauled piping system, of which this unit is a part, this particular company has standardized on welding of all pipe joints, wherever practical, and they are of the opinion that there are not many places around a refinery where this is not the best method.

Sales Advantages of Welded Products

By **J. J. FIECHTER**

✦Paper presented at the Annual Meeting, International Acetylene Association, Philadelphia, November 16, 17 and 18, 1932, by J. J. Fiechter, Works Manager, Heintz Manufacturing Company, Philadelphia.

YOU who are familiar with the development of the American passenger automobile realize that tremendous strides have been made in body construction during the past twenty years. This is especially true of low-price cars.

History of automobile development began with types closely resembling a horse-drawn buggy and phaeton. They were in fact and in name "horseless carriages." The bodies were built of wood and finished with the time-honored arts of the coach builder. But no matter how carefully built of seasoned wood with the best joinery they soon racked apart and became a nuisance and an eyesore. Speeds of twenty-five or thirty miles an hour over the dirt and macadem highways produced stresses that no wood construction could withstand for the time cycle demanded. The owner of the old-time buggy rarely drove it more than ten miles a day, perhaps not more than two or three times a week. His yearly driving might reach 1000 miles, most of it at speeds not faster than eight miles an hour.

Hence, auto body builders soon discovered that the construction of the coach builder required radical changes and improvements to meet the conditions of faster traffic, and 10,000 to 20,000 miles driving per year.

Then the use of metal, usually aluminum as a veneer over the wooden framework, began with resulting great improvement in strength and durability. However, as the public began to buy cars in large numbers and production costs were reduced to meet the demand, the

use of sheet steel steadily displaced aluminum. It had the advantages of greater strength with flexibility at a lower cost and also required a simpler framework. Welding then entered the picture, which brought about still more economy in the manufacture of bodies and also gave the user a jointless or monolithic construction that with ordinary care would outlive the engine and running gear and, last but not least, the period style.

About ten years ago, the open or touring type of body began to give way in the low-price car field to the closed body type, due to public demand and improvements made by presswork and welding, which enabled the body maker to produce closed bodies at low cost.

To say that the modern sedan or four-door type of closed body is a marvel of sheet steel construction is no exaggeration. Weighing only approximately 100 lb., not including doors, glass and lining, it is a self-supporting structure. Moreover, it affords a degree of bodily protection little short of marvelous, as has been repeatedly demonstrated in accidents.

Now that is what a purchaser of a modern car gets, often without realizing that he enjoys the use of a durable, safe construction at low cost because it is welded. So when I was asked to talk to you on the sales advantages of welded products, I felt somewhat dubious of conveying a very convincing argument that there are advantages other than reduced costs and superior products.

That these advantages are very great cannot be gainsaid, but you soon run out of words when telling them. They somewhat resemble a patent which has two or three basic claims broadly drawn. You read them quickly, but they mean a lot. So it is with welding in manufacture and construction. You can quickly tell the advantages but you say a lot in telling them.

Design

Welding has made it possible to simplify the design in so far as it permits parts to be joined by welded joints, thereby eliminating the need of holding flanges or rivets or bolts and giving an assembly set up from the standpoint of cost and construction, which would not be developed if rivets, screws or bolts were used.

Speed and Preparation for Production

In the automotive industry, the time required for getting into production after the final designs have been released is of vital importance. When the product is designed for welding, it automatically reduces the preparation time both in the construction of the finished piece, as well as in the designing of the tools, jigs and fixtures. In the place of having to work out a lot of detailed dimensions, a lot of this work can be covered by notations designating welding.

Cost of Preparing for Production

Again, a decided saving takes place due to the following conditions: simplified design in the piece construction necessitating fewer dies, also reducing the number of tools; jigs and fixtures required, due to the rapid production which is brought about through welding; reduced overhead cost by shorter time spent on job; often the possibilities of further reduction of assembly and welding jigs, because of the fact that some of the welding operations are produced so rapidly that one fixture will take care of more than the requirements.

Appearance

The appearance of an article has considerable bearing upon its possibilities for sale. In this connection, an automobile body, which has been welded completely throughout, eliminates unsightly rivets or screws and gives a clean-cut appearance. The welding also facilitates working out a design embodying smooth, graceful lines, free of joints, clearer vision and ideal for exterior finishes.

Durability

It is a known fact that welded units and assemblies are extremely durable, and a properly welded body can never loosen or fall apart. As a matter of fact, a welded assembly, to all intents and purposes, is equivalent to a one-piece job and can assume considerable more abuse than a bolted unit.

Production Costs

To produce bodies, or sheet metal parts for modern cars at present prices, would be an utter impossibility without welding. To give an idea of the economical advantages in the production of welded parts, a plant normally consuming between 25,000 and 30,000 tons of sheet steel per year, ranging in gage from possibly 0.025 to 0.078 in thickness, has produced approximately 7,500,000 stampings or parts, 95% to 97% of which are joined together by means of welding, employing between 40 and 50 acetylene welders, 20 to 25 arc welders and 80 to 100 spot welders. In other words, this small group of welders is responsible for joining together so many millions of parts in a year's time, which was only made possible by the application of welding.

Another very important feature of welding is in connection with the building of jigs and fixtures. In so many instances, it is possible to use ordinary steel plate with blocks which are placed around a wood frame or template and properly located without having to resort to the expensive operation of the mechanic, making all kinds of measurements in order to obtain accuracy. In one particular instance, we had occasion to build approximately 150 assembly and inspection jigs, and the aforementioned method enabled us to put them through on a production basis at a cost of possibly one-third of what would have been involved had these same jigs been built up from castings. Furthermore, in building jigs in this manner, it practically eliminates any and all chances of error.

In conclusion, I would like to express the opinion that the time is rapidly approaching when every manufacturer of sheet metal products must give more intensive thought to the application of welding in fabricating his materials, in order to be able to meet with competition from the standpoint of simplicity, cost and appearance.

Flame Centering of Solid Round Billets

Conditioning, Shaping and Machining of Carbon Steel by Oxygen

By H. H. MOSS

✦Paper presented at the Fall Meeting of the American Welding Society in Buffalo, October 3, 1932, by H. H. Moss, Development Section, Engineering Department of The Linde Air Products Company.

UNTIL within the past few years the oxyacetylene cutting process has been used primarily as a severing tool. In this capacity it performs a wide variety of cutting operations in all commercial thicknesses and at very low costs. In a number of respects, particularly those relating to cuts of irregular contour in rolled or forged steel, this process has developed to be of unprecedented utility, being capable of tracing, singly or in multiple, intricate geometric shapes or patterns within very narrow tolerances.

The accurate performances of this new cutting tool in the heavy gages has earned for it the credit of having greatly expanded their commercial range, for it has enabled economical preparation of these heavy gages for fabrication, thereby encouraging their use in fields hitherto closed, such as machinery housings, major pressure vessels, structural slabs and plates.

The type of cutting referred to may be characterized as normal cutting or severing for the reason that the cut is generally made through the part as at (*a*), Fig. 1, leaving edges whose surfaces lie in a plane 90 deg. to the surface of the part cut, except when a bevel cut is particularly sought. The scope of normal cutting has grown to a degree where it is more proper to refer to it as the "Industry of Flame Cutting," for it is as essential to the art of metal working today as any of the allied primary formative operations and is as extensive in its applications.

Alongside of this industry another, also utilizing the oxyacetylene cutting principle, has begun to take shape. It may properly be termed the corollary or sequel of the former, for it differs from the former not fundamentally, but simply in the character of cuts which it produces. Its main distinction is its use of a tangential positioning of the cutting oxygen stream as at (*b*), Fig. 1. This change in the position of the cutting oxygen stream with respect to the work is responsible for an entirely new range of oxyacetylene cutting operations. Due to their similarity with many operations of customary tool machining, they have been collectively assembled under the common title, "Flaming Machining" in contrast with flame cutting and will be so classified in this discussion.

The developments within this new branch during recent years, though only partially commercialized as yet, are of such economic importance from the industrial

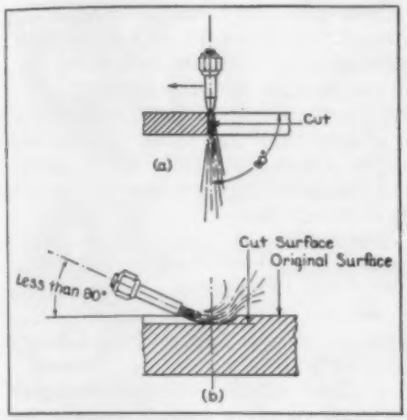


Fig. 1—Relative Position of Blowpipe Nozzles (a) for Serving and (b) for "Flame Machining"

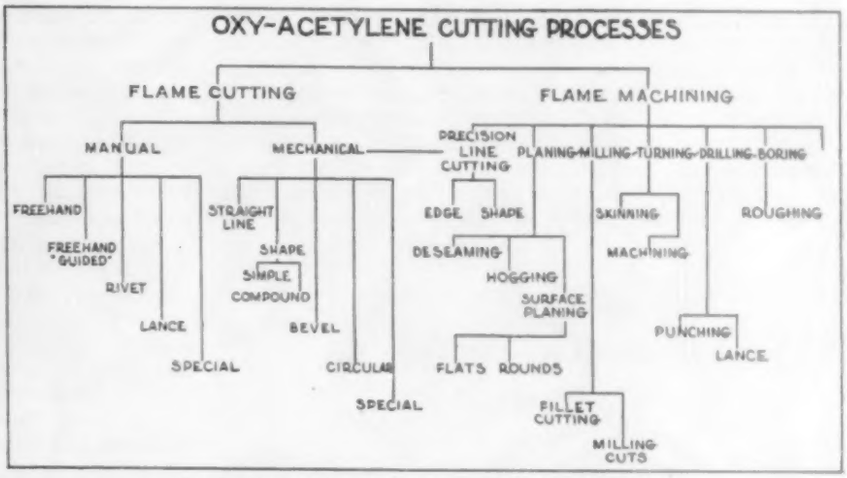


Fig. 2—Classification of the Oxyacetylene Cutting Process

Table 1—Rate of Linear Travel in Straight-Line Cutting of Low-Carbon Steel Plate

Thickness of Metal, In.	Speed Range in Linear Feet per Hour Manual	Mechanical
1/4	90–140	107 –140
1/2	85–130	89 –130
1	50–71	64 –95
2	33–46	44 –60
4	18–27	30 –43
8	11–19	21 –27 1/2
12	6–13	13 1/2–14 1/2

NOTE: The range in speeds given in this table represents the nominal differences in efficiency of unskilled and skilled workmen, conditions of material and facilities for the performance of the work.

aspect as to establish their position permanently in the structure of oxyacetylene applications and to warrant their inclusion in any general discussion of the art of oxyacetylene cutting.

While the scope of this paper justifies detailed consideration of the processes of flame cutting over a wide field, it is my object at this time to generalize the subject as a whole and to deal more specifically with its widening scope under the influence of some of these later developments, in order to invite attention to the present trends of oxyacetylene cutting, the many classes of work which it has embraced and its new fields.

The diagram, Fig. 2, undertakes to classify the applications of oxyacetylene cutting. It is divided into two main branches, "Flame Cutting" and "Flame Machining," within which are sub-tended the respective applications, both commercial and experimental, within present range.

On the left-hand side of the diagram under flame cutting are arranged those operations whose elementary function is largely that of linear oxidation. The result of their performance (with one exception of that produced by the sub-division, rivet cutting) is a relatively narrow slot or kerf varying in width as the depth of the part cut, the diameter of the cutting oxygen nozzle and as the oxygen pressure during the cutting operation being approximately 1/16 in. and less for the light gages, and 1/2 in. or more for very heavy and unwieldy masses of steel. Over the range of 1/2 in. to 6 in. thicknesses, the kerf width for guided cuts varies between plus or minus 3/32 in. and 7/32 in.

The rate in which the cut is made varies primarily as the thickness of the cut is perpendicular to the surface of the part being cut. If not, the rate will vary as the cross-sectional area of the cut. The rate is usually ex-

Fig. 3—The Cutting Rate Expressed in Pounds of Metal Removed per Unit of Time

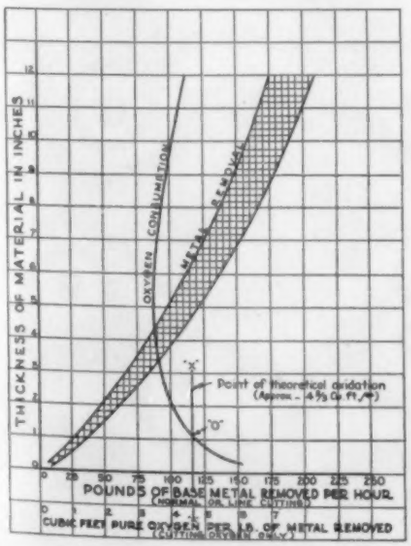

THICKNESS OF MATERIAL IN INCHES
OXYGEN CONSUMPTION
METAL REMOVED
Point of theoretical oxidation
(Approx. - 4 5/8 Cu. Ft. per lb.)
POUNDS OF BASE METAL REMOVED PER HOUR
(NORMAL OR LINE CUTTING)
CUBIC FEET PURE OXYGEN PER LB. OF METAL REMOVED
(CUTTING OXYGEN ONLY)

Fig. 4—The Range of Normal or Line Cutting as Practiced Today

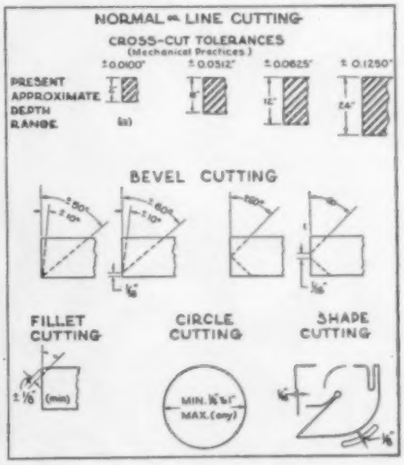
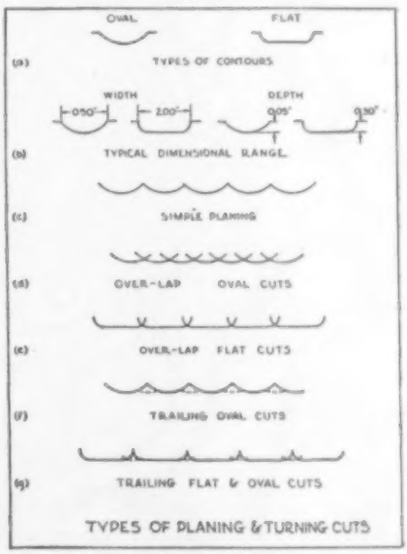


Fig. 5—Types of Planing and Turning Cuts Produced by "Flame Machining" Operations



pressed in terms of linear feet per hour. Data for manual and mechanical operation of the cutting tool for thicknesses from $^1/_4$ in. to and including 12 in. are shown in Table 1. From the more fundamental view-point, the rate measure, pounds of metal removed per unit of time, though somewhat difficult to summarize, is quite useful for purposes of comparison as will later be indicated and, therefore, Fig. 3, which is an approximate construction of these relationships, has been prepared to indicate the

Fig. 6—Steel Plate with Five Typical Deseaming Cuts upon Its Top Surface

number of pounds of metal removed per hour on the basis of normal kerfs and the identical range of manual skill as expressed in Table 1.

The residues of normal cutting are composed largely of iron oxide in the form of the magnetic oxide Fe_3O_4 and iron or steel which has been blown from the kerf in the molten state, the latter usually increasing as the thickness of the part cut.

The oxygen *expense* of normal mechanical cutting, exclusive of that expended in the preheating flames of the cutting nozzle, varies approximately between $3^1/_2$ and 6 cu. ft. per lb. of metal removed. The relation is expressed in Fig. 3 by the consumption curve, superimposed thereon, from which it may be observed that as the thickness of the cut increases beyond the critical point (*O*), the greater is the amount of metal removed as molten steel up to the region of thicknesses of approximately 6 in. Beyond this the oxygen loss increases slightly, which causes the curve to incline in the direction of higher oxygen *expense*. It may also be observed that as the thickness decreases below the critical point, the curve again swings rapidly toward higher oxygen *expense*. This loss represents free or unutilized oxygen, due to the relatively short path of the cutting oxygen stream through the material as compared with the relatively high velocity of the cutting oxygen. The critical point on the oxygen *expense* curve has been assumed to be about the point (*O*) where the perpendicular, *X-X*, crosses the consumption curve, the line *X-X* being the relative position in the chart for the point representing the number of cubic feet of oxygen theoretically necessary to oxidize one pound of iron or steel. While it is likely that theoretical oxidation is never accomplished in actual practice, there being some molten steel and some free oxygen in all cutting residues, there is a point in any such chart as Fig. 3 where the effects of these two properties neutralize and give coincidence with a line representing the theoretical consumption of approximately $4^2/_3$ cu. ft. per lb. of steel oxidized. The coincidence occurs in the neighborhood of base metal thicknesses of $^3/_4$ to $1^1/_2$ in.

Metallurgically, the effect of flame cutting upon the usual grades of iron and steel is to alter the grain structure about the surfaces cut. This is due to the rapid chilling usually following the operation. The alteration is highly marginal, but sufficient to increase the hardness of the cut surface unless specific precautions are taken to overcome this. In the case of steels of 0.30 carbon and less, this physical change has been shown to be beneficial, due to the toughening action of the heat treatment. For steels of higher carbon, however, the altered structure sometimes gives rise to fine surface checking, necessitating either the prevention of the hardening effect or its removal after cutting. Preheating of the part prior to cutting or annealing subsequent thereto are both practiced at the present time, the choice being largely a shop matter as long as the specified desired physical properties are not violated. Preheating to a black red is generally more than sufficient, whereas in annealing the metal is required to be heated to beyond its critical temperature in order to restore equilibrium to the grain structure.

For all practical purposes it may be established that 0.30 carbon is the focal point about which metallurgical concern in flame cutting should occur, the lower carbon bracket being benefited and the higher one requiring analysis and the guidance of experience or laboratory direction for assuredly satisfactory results. In either case the economics of flame cutting are proportional, for as the operation becomes more involved, the greater becomes the value of the work accomplished by the cutting operation.

The fact that flame cutting does not impair the commercial value of low-carbon iron and steel is responsible for its universal adoption as a tool for conditioning and shaping. However, its vast technical progress in the fields of fabrication is due to the accuracy which has been attained in modern cutting practices. These are capable of producing cuts sufficiently uniform with respect to linear regularity and squareness to pass the requirements of final edge finish for innumerable objects of plate and shape constructions. Thus it is that flame cutting performs a dual service, "severing" and "finishing."

The depth range of flame cutting would seem to be unlimited. To date, thicknesses up to 8 ft. have been successfully severed. However, it must be remarked that the character and accuracy of cutting does not hold uniform throughout the full depth range. There are three distinct stages. The first, in which the degree of uniformity and squareness of cut is accurate to within a few thousandths of an inch, expressed as precision line cutting and appears in the right-hand branch of Fig. 2. Its particular range at the present time, though not restricted to these dimensions, includes all gages up to 2 in. The second stage is that which has been commercialized by mechanical cutting devices of one form or another and includes all gages up to 24 to 28 in. The accuracies of this stage vary from $^1/_{32}$ in. for the lighter gages to $^1/_4$ in. for the extreme upper end of this range. It is in stages 1 and 2 that the dual service is performed. The third stage is that which has been developed by manual cutting in one form or another. When done solely by hand blowpipes, its depth is about the same as that of the mechanical range, but requires greater dimensional tolerances; whereas, when aided by the oxygen lance, the range is increased indefinitely to

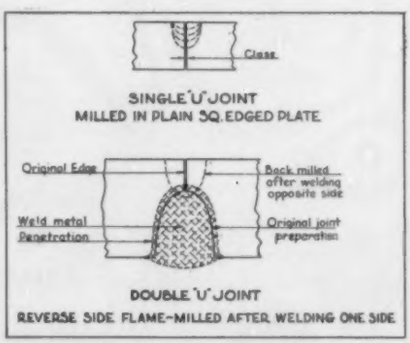


Fig. 7—Flame Milling Applied to the Beveling of Plate for Welding

about 8 ft. These cuts are usually not regarded from the standpoint of surface uniformity and, therefore, the tolerance of cut is generally of minor consequence.

From the operating standpoint, there are a great number of applications and means whereby to perform them; in fact, too many to embrace in the space

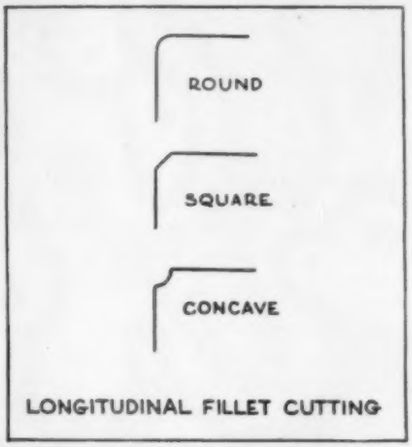


Fig. 8—Longitudinal Fillet Cutting Is Another Operation Included under "Flame Machining"

available in this paper. The range of normal or line cutting as practiced today, however, is shown diagrammatically in Fig. 4.

With cutting machines developed for practically all general forms of mechanical translation, the present developments in linear flame cutting are largely toward improving the design and construction of the cutting devices for greater cutting accuracy, portability and the widening of the detail range of both the portable and stationary types of semi-automatic and automatic cutting machines.

On the right-hand side of Fig. 2, under "Flame Machining," are arranged those operations whose elementary function, with the exception of two applications, is largely that of surface oxidation much in the form of tool planing. They involve means for removing wide strips or linear areas from the surfaces of steel stock and logically, therefore, classify under a different branch of cutting application from normal or line cutting.

To these strictly machining types of cuts have been added "precision cutting" and "flame boring," the former being a refinement of mechanical line cutting in the flame cutting branch and the latter being as yet an experimental development of the ordinary flame cutting practice of drilling a hole through a piece of work. Their position in the right-hand side of Fig. 2 is due to the precise surfaces obtainable by the former as indicated in Fig. 4 (*a*) under "Line Cutting" and the accomplishment of a circular hole by the latter without resort to line cutting, much as an ordinary punch produces a hole.

As previously cited, not all of the operations subtended under "Flame Machining" have been commercialized at the present time. Those which have are so noted as their class is individually discussed. Those sub-tended under planing such as deseaming, hogging and surface planing have all had commercial adaptations, as have some of the milling cuts. The general style of these cuts is shown diagrammatically at (*a*) and (*b*), Fig. 5. Their individual dimensions are the product of combinations of the diameter of cutting oxygen orifice, the cutting oxygen velocity, the rate of travel of nozzle with respect to the work and the angle of inclination of the nozzle with respect to the surface of the work and to the surface of the cut. All things being equal as to angle of nozzle, rate of travel and orifice size, the cross-sectional dimensions of these cuts increase with increased oxygen pressure, also the cross-sectional dimensions alter responsively to altered oxygen pressure, provided the conditions of preheat are properly maintained.

The process is being used extensively today for removing cracks or seams in billets, slabs and rounds enroute to the various finishing departments of the steel mills (see Fig. 6) and in the steel foundry for exploring and cleaning up cracks and sand holes, removal of superfluous metal in castings due to defective conditions at the

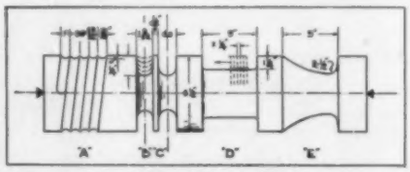


Fig. 9—Types of Milling Cuts Possible to Make by Multi-Phases of the Planing Nozzle

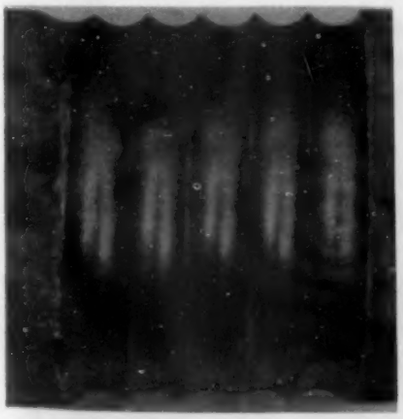


Fig. 10—Photo of Detail (*A*), Fig. 9

Fig. 11—Photo of Detail (*B*) and (*C*), Fig. 9.

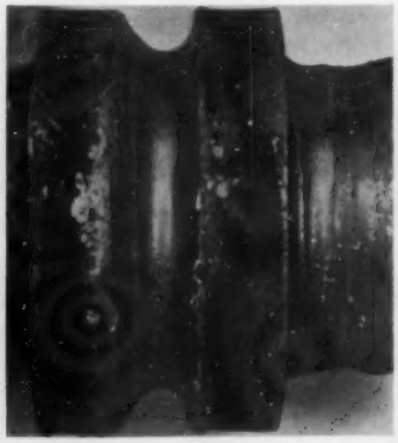


Fig. 12—Photo of Wall of Cut (*D*), Fig. 9

time of pouring and the removal of risers and sprues whose location makes for difficulty in their removal by ordinary line cutting. Other applications under development consist of rough planing either by means of single cuts or by gang assembly of the planing nozzles. Uniformity of flame-planed surfaces is approached by overlapping of the cutting oxygen stream or by trailing cuts as illustrated diagrammatically at (*d*), (*e*), (*f*) and

Fig. 13—Photo of Detail (*E*), Fig. 9 Flame Centering of Round Solid Billets

(*g*) in Fig. 5. Inasmuch as the tolerance of this type of cutting can be controlled within reasonably close limits, it is not out of order to state that rough surface planing to at least within $^1/_4$ to $^1/_8$ in. of finished dimensions is near at hand.

A further development of flame planing which has been classed under "milling" consists of sinking a planing cut by means of multi-passes of the planing nozzle to produce cuts like those shown at (*B*), Fig. 9.

Cuts like these find practical value in the preparation of joint edges for certain types of butt welding as shown in Fig. 7. They can be made either before or after welding. Under this same classification of "Flame Machining" has been included longitudinal fillet cutting, in contradistinction to edge fillet cutting as indicated in Fig. 4 under line cutting. This is a tangential application which is being developed to provide various fillet contours, as shown diagrammatically in Fig. 8. These cuts find practical value in improving the appearance of the abrupt edges of line-cut objects.

Fig. 14—Precision Cut $1^1/_2$-In. Low-Carbon Steel Bar Bent 150 Deg. without Signs of Fracturing

Flame turning is next, for it combines both of the previous operations above discussed with a facility which has been shown experimentally to lend itself readily to many lathe turning operations of roughing. The range of this branch is likely to be very wide, judging from recent experimental developments on round stock. Figures 9, 10, 11, 12 and 13 show diagrammatically and pictorially a few of the types of cuts which have been accomplished by flame turning.

The cut at (*A*), Fig. 9, is a simple application of tangential cutting under compound lathe motion. It was made by a single pass of the cutting oxygen stream. However, its individual threads or races can be deepened at will by repeating the operation concentrically and by suitable adjustment of the cutting nozzle and the cutting oxygen velocity.

The cuts at (*B*) and (*C*) are milling cuts readily produced by multi-pass planing, (*B*) evidencing general dimensions and (*C*) the degree of control which can be maintained.

Cut (*D*) indicates a range of single-pass cutting produced by a compound angle setting of the cutting gas stream. For cuts of this type, the axis of the cutting nozzle is made tangent to both the surface of the stock being cut and the desired vertical face of the cut to be made. Such cuts are started by first milling a slot similar to (*B*) as shown dotted in (*D*) which provides opportunity to apply the compound setting against either wall of the milled slot.

Cut (*E*) is merely a modification of (*D*), illustrating roughly the flexibility of flame turning. In this case the contour of the cut has been changed by means of a rotating action applied to the cutting nozzle while the work is rotating to provide uncut material to the nozzle. From these experiments it was obvious that, having

Fig. 15—A $1^1/_4$-In. Low-Carbon Steel Plate Re-cut by Precision Cutting to within $^1/_{16}$ In. of the Original Flame-Cut Edge and Maintaining Same Trueness as the Original Cut Edge

suitably sensitive and flexible mountings for the cutting devices and feeds, any desired profile could be produced. It was a further observation that the responsiveness of the material to the cutting operation was, in a large measure, proportional to the temperature of the material in the region immediate to the cutting zone. In other words, contour, uniformity and flexibility of flame machining are closely allied to the temperature of the work and improve as the temperature increases.

Under the classification, "Flame Drilling," Fig. 2, fall two developments of flame machining which promise to render much valuable service in the way of producing holes for various purposes.

Flame punching, now under development, seeks to bore a relatively straight hole by the principle of a single concentric cutting operation. Large size nozzles and reasonably high pressures are required and while efforts to date in this direction have not produced an entirely satisfactory bore, the results have nevertheless been very encouraging and indicate that a practical alignment tolerance will likely be attained.

A form of flame punching, which has recently been somewhat commercialized and which makes a close approach to the full parallel punch, is the flame centering of solid round billets in preparation for the piercing operation in the manufacture of seamless tubing. The operation of flame centering is illustrated in the picture at the head of the article.

The sub-division "Lance" under "Flame Drilling" does not refer to major oxygen lance operations which are covered by the sub-division under "Manual Gas Cutting." Instead, it covers the use of a miniature lance to bore a long concentric hole through a piece of stock for the purpose of clearing a channel for subsequent flame boring. The operation is not unlike that of the major lance except that it utilizes light carbon burning types of blowpipe handles fitted with suitable lengths of very small diameter black iron tubing. The device is capable of producing relatively uniform holes of considerable depth.

The final classification has been entitled "Flame Boring." It is one which is altogether experimental to date, but possesses very practical aspects for general boring operations. Fundamentally, it consists of a modification of the operation resulting from the compound setting of the cutting nozzle which produced the deep single pass cut shown at (*D*), Fig. 9. Only in this classification it is applied to an internal annular surface, and promises to remove the metal at rates comparable with that of the flame turning operation illustrated in Fig. 12.

On the extreme left-hand side of the "Flame Machining" branch of Fig. 2 has been added "Precision Cutting,"

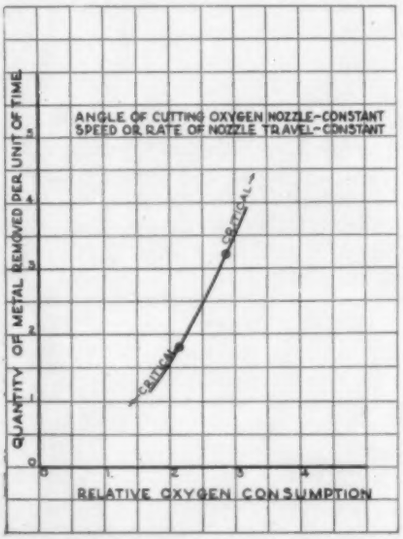


Fig. 16—The Relation of Oxygen Consumption to the Quantity of Metal Removed per Unit of Time for "Flame Machining" Operations

which classification, as previously explained, was made due to the precise uniformity which has been developed in recent line cutting experiments seeking the lower limit of cutting tolerances. As brought out by J. R. Dawson in a paper presented before the New York Section of the AMERICAN WELDING SOCIETY in October 1931, precision cutting to within a few thousandths of an inch was obtained in $1^1/_4$ in. thick plate through careful set-up of standard cutting apparatus. These experiments have thrown considerable light upon normal or line cutting and have confirmed the belief that many milling operations such as those applied in the structural field will, in the not too far distant future, be entirely feasible by this means.

Two illustrations of Dawson's work are given in Figs. 14 and 15, the former showing a precision cut on flame-milled bar bent through 150 deg. without evidence of fracture or any cracks in the flame-cut edge; the latter showing a $1^1/_4$ in. low-carbon steel plate re-cut to within $^1/_{10}$ in. of the first flame cut, the alignment and squareness of the cut edge being equal to that of the original cut. These particular cuts were true as to squareness and alignment to within 0.01 of an inch.

The rate of tangential cutting in terms of pounds of metal removed per hour varies with different types of cuts. As yet there does not seem to be any simple formula or criteria for predetermining this data. For the simple type of cut shown at (*A*), Fig. 9, the rate varied between 500 to 600 lb. of base metal per hr., which could doubtlessly have been considerably increased judging from the responsiveness obtained during these experiments. Cuts like those shown at (*B*) and (*C*), Fig. 9, were made at rates of 450 to 550 lb. per hr.; whereas for the cut (*D*), illustrated in Fig. 12, the rate varied between 1200 to 1800 lb. per hr. From the standpoint of comparison with tool machining, the rate of volumetric displacement in making the cut illustrated in Fig. 12 with high-speed steel cutting tools would probably be in the neighborhood of 550 to 650 lb. per hr. for soft steel, 250 to 350 lb. per hr. for medium steel and 115 to 160 lb. per hr. for hard steel.* In the simple planing operations shown in Fig. 6, rates varied between 500 to 1000 lb. per hr. with single nozzles. With the aid of compound nozzle operations, there would seem to be no limit to the possibility for increased removal rates. Just where these rates will ultimately settle is hard to determine at this time. It has been indicated, however, that for any particular cut by flame machining, there will be a corresponding set of cutting conditions involving velocity of the cutting oxygen stream, proximity and angle of inclination of the stream, rate of nozzle travel and feed that will give the most satisfactory results as to lead or workability, cleanliness of slag blow and economy of labor and gases. In other words, there will be definite practical limits for each combination beyond which the operation becomes either too critical or totally uncontrollable for practical objects.

The oxygen *expense* of tangential cutting varies also with the different types of cuts, but compared with that of normal or line cutting is considerably less. There are two reasons advanced to account for this:

1. Likelihood of more base metal removed in the molten state, and
2. Greater degree of surface impingement of the cutting oxygen stream.

Over the range of mechanical flame machining performed to date the oxygen *expense* has varied between 2 to $2^3/_4$ cu. ft. per lb. of metal removed and with indications of still further oxygen economy as more experience is gained. For any set of constant conditions as to the size of the cutting oxygen orifice, angle and proximity of cutting nozzle and rate of travel of nozzle with respect to the work, the oxygen *expense* varies almost directly as the volume of metal removed per cut, that is, the volumetric displacement increases with increased oxygen pressure for the same size cutting oxygen orifice, all other things being equal. This relationship is shown in Fig. 16. It is also true that for every set of conditions, as just noted, there is an intermediate range of pressures wherein the machining results are satisfactory as to regularity and cleanliness, and beyond which the conditions become critical, resulting in irregularities and other unsatisfactory conditions.

With preheated stock, the oxygen *expense* will doubtless be reduced well below the figures of 2 to $2^3/_4$ cu. ft. above mentioned, at the same time the responsiveness of the work to the machining flame or flames should be

* NOTE: These volumetric displacements are obtained with cuts $^3/_8$ in. in depth, with 0.0625 in. feed and surface speeds averaging 130, 65 and 30 ft. per min., respectively.

rendered considerably more sensitive. Preheat should, in addition, both narrow the cutting tolerances and make for closer control of the cutting action.

From the metallurgical standpoint, preheating performs another very valuable service in flame machining, namely, that of retarding the rate of cooling of the base metal which has been heated in the region of the cut to beyond its critical temperature. Quenching from this point in the temperature scale, which can be retarded by suitable preheat, produces increased hardness in proportion to the carbon content and makes subsequent machining operations difficult or expensive. Another advantage of preheat is that it prevents the development of unequal stresses in the part being machined, the action being one of compensating for or otherwise subordinating those which concurrently form behind the cutting operation. Thus it is that preheating rather than postheating is looked upon as the better of the two and a function of the operation of flame machining that will in time, it is believed, be looked upon as a substantial aid and benefit to the production of shaped parts.

It has been observed that the harder steels, or those having the higher amounts of combined carbon, responded more readily to the action of flame machining operations than those of low combined carbon, such as the low-carbon steels, indicating that the economy of flame machining of carbon steels will improve as the hardness of the base metal increases.

When it is considered that power is needed only for turning the stock and none for performing the cut, as the operation of flame machining is fully free turning, there would seem to be many opportunities to effect economies by machining by this new method, especially with the harder steels.

Each operation is more or less a problem unto itself, calling for a coordination of nozzle tooling and metallurgical control to produce a result satisfactory for the subsequent shaping and final tool finishing or grinding of the part in question.

The fields indicated by Fig. 2 have thus been tentatively surveyed and while the commercial range of the flame cutting branch is by far the most extensively developed at present, that of the flame machining branch is tending to become equally as broad and none the less valuable as a formative tool for the preparation and shaping of the carbon steels. Its rate of progress aside from the operations of deseaming or desurfacing and rough flame hogging, will, to a large extent, be proportional to the degree of precision commercially obtainable by the machining nozzle. The conjecture suggests a rather important development of flame tooling similar to that which attended the development of modern machine tools a decade or so ago.

Shielded Metallic Arc Process

By C. J. HOLSLAG

✦Mr. Holslag is connected with the Electric Arc Cutting & Welding Co.

THE covered electrode shielded arc process which has been struggling for favor in this country for a little less than twenty years is now becoming very popular. In fact, so popular that it is often used wrongly. Weld deposits made correctly by this method are not only better than any welding process but they are better than any steel made by any process. Riding on the wave of popularity are such manufacturers who say, "Oh yes, buy my rod and all such good results are obtained," when the truth is that a very careful procedure technique must be followed in order to get such bettered deposited metal.

This process consists of covering the electrode so as to shield the arc and provides a refining atmosphere and, in addition to the speed and refined metal advantages gained by this process, layer annealing is used to obtain better results than were possible by any previous means, including the gas arc process or any fusion process. From a practical standpoint, it is perfectly feasible to weld a narrow V and do thick work with this process. With the covered electrode metallic arc, it is entirely possible and quite common practice to weld two to six inches thick and many jobs have been done twelve to twenty-four and even thirty-six inches in depth. The process consists of making a suitable V-, U- or bell-shaped groove, either double or single, with projecting lips so as to approximately register to hold the first deposit. Immediately after making the first deposit, the combination of peening and caulking removes the dross and cleans for the next layer and forces out the deposited metal to the original dimensions of the U or groove. This relieves contracting strains and also, by what might be described as a molecular rearrangement, takes the internal stresses out of the deposited metal and also the parent metal. This latter action is rather hard to explain but it is a well-known fact especially with boiler workers that rattling the metal immediately after the welding keeps the weld from cracking in difficult cases where such troubles are common.

Continuing with a clean and smooth surface, the process consists of depositing layers one after the other, repeating the chipping, cleaning, forging and remelting, the wonderful action being that each layer refines the layer beneath it and the edges of the parent metal that have been affected by the fusion so that the final deposit is better than any steel or metal that has been made by any process. It is not at all difficult to exceed the strength of the best steel using this process with a base deposit metal of very ordinary wire. Not only is the strength exceeded but also the other physical qualities are bettered or equal.

In order to obtain the results obtained above, of course, experienced supervision or accustomed operators or both must be used and the metal must be melted to just the correct fluid stage that gives the correct thickness of layer and refining action, and it is evident to make the entire deposit correct that one or, in the case of a double V, two welds must be made which are either abandoned or machined off. This refining action and removal action can be accomplished by a cutting electrode, that is, the cutting arc can be passed over the work, some of the metal removed, or none removed and the final action obtained. This cutting electrode is also very essential in this process in double V or work that has to be sealed on the inside. The rod is used to remove the uneven, penetrated parent or dribbled welded metal and the grooves, so made and filled up by the regular process, herein described. It will be noticed, from a practical

standpoint, that this method is apparently very easy but as a matter of fact experience and practice can only give the results described. For instance, if such a covered electrode is used, not as described above, say, in a single layer or even in a double layer with the last layer expected to carry part of the strain, results, perhaps inferior to ordinary welding, may be obtained except that this covered electrode can be used for speed where elongation and ductility are not required. In other words, this covered electrode can be used in amazing current densities and almost unbelievable speeds of deposit where the special physical properties desired above are not necessary. Under some conditions, both speed and desirable results can be obtained in one layer and always in two or more layers. For instance, if the work is just thin enough to be heated to the correct normalizing temperature by one or two deposits, then the desirable results can be obtained in one layer with amazing speed but this is generally only reliably possible in automatic work because both the speed and current deposit must be held constant at the correct temperature, i.e., 1150° F. Approximate results, much better than ordinary welding, can be obtained with an intelligent operator holding the temperature from color or at the correct value of between 1100 and 1200, the weld being made in one or more passes.

With this process, especially on thick work, a normalizing oven is necessary. This can be a temporary or permanent brick affair where the temperature is held between 1100 and 1200 and into which the object being welded is rushed when it shows signs of the heating stresses overcoming the unfinished weld deposit. Preheating in such a furnace would also help but practical consideration of being able to "set up" the work while cold generally precludes this.

The best way would be to preheat but with hand welding this is out of the question as you cannot stand near enough to work on it properly. It might be done with automatic welding but it would have to be followed with automatic caulking; that is, an automatic welding head would be followed by an automatic peening tool so that the contraction strains would not pull the piece out of alignment or crack it.

The working it "hot" is a dream of how it might be done. Practically, manual welding is started in the morning and around 3 o'clock or 2:30 on a hot day, it gets so unevenly hot it is put in the oven, the heat turned on, until evenly at 1150° F. and then left there overnight without heat; that is, cooling slowly, taken out in the morning, and work started on it again. It takes about an eight-hour day to get the piece so it requires normalizing. This is shown by the skin of the steel puckering and cracking off. It is then high time to put it in the furnace and call it a day.

When the work is all completed, the job is put in the furnace and kept at a temperature of 1150° for as many hours as there are inches of thickness in the heaviest place. It is then allowed to cool off in the oven and is ready for remelting or, if completed, for eternal life.

The usefulness of peening and caulking has been a large factor in the success of the shielded arc process. In the early stages of welding in the United States peening with arc welding was used extensively but for a great many years thereafter it sort of fell into disuse because of a lack of understanding of its valuable properties. For instance, all the old-time boiler workers and such manufacturers that used arc welding in boiler work knew that stress relief was obtained by caulking a weld and that better results could be had both as to removal of stresses and grain refinement by peening the metal

Table for Heavy Section Steel Welding

Plate Thickness, In.	Amps.	Volts	Electrode, Size	Length of Rod	Lb. per Hour	Groove, Width	Lip Thickness
3/8	300	27	3/16	15	5	1/2	1/8
3/4	350	30	7/32	16	7 1/2	5/8	1/8
1	400	33	1/4	18	10	3/4	5/32
1 1/2	500	36	9/32	20	15	7/8	5/32
2	550	38	5/16	22	20	1	3/16
3	600	40	11/32	24	25	1 1/8	5/16
4	700	42	3/8	30	30	1 1/4	7/32
5	750	44	7/16	36	35	1 1/2	1/4

together with layer deposits in a V'd-out section. An old boiler maker trick in welding was the rattling of the metal by a bobbing tool or similar means that in the welding of a patch its cracking would be prevented. This old use, recognized now as grain refinement and stress relief, has again become important in the welding of heavy sections such as steam boilers, air pressure vessels, oil refining equipment, etc., and a résumé of the best methods for using this method is not out of place although the system described will be "old" reading to many.

The ordinary boiler chipping hammer is the best tool and a dull chisel can be used although special ground tools shaped to fit the surface are better but not necessary. Air pressure hand caulking can be used too and an air hammer is better by far. Rather medium hard but not "forcing" blows should be used and in peening a weld, the same as caulking a riveted seam, a great deal of judgment must be used. For instance, if metal is actually forced down into cavities and imperfections closed by this method, there is more harm than good done. The idea of peening is to relieve effects of contraction of the welded metal by these means:

1. Forcing of the deposit to fill the original space and maintain the gap or V dimensions.
2. Stress relief by grain refinement which might be described as settling into place of the molecules while under motion due to the hammering.
3. Improvement of the metal by "working." This effect is well known but of least importance on account of the remelting of the deposit.
4. Another very important effect is the cleaning of the surface of slag or dross and peening should be done so as not to include slag in succeeding layers or flow the metal by heavy or too many blows so as to fold over itself to cause faults.

The cleaning of welds for subsequent layers is absolutely necessary but it has not always been so realized. Of course, in addition to peening and caulking, there is sand-blasting and other mechanical means of cleaning but probably the most popular is the chemically fluxed electrode which leaves only such dross that a hand- or motor-driven brush can remove.

Summary of advantages of shielded arc:

1. Better metal deposit than possible by any fusion means yet discovered.
2. Ductility and elongation equal to best "Marine" steel.
3. Elimination of oxides, nitrides, cyanides and other deleterious compounds.
4. Arc process "easy" to handle and speed of deposit greatly increased.
5. Large and heavy work made possible and more smaller work brought within the scope of welding.
6. Either direct or alternating current can be used with this process.

Weight and Cost of Steel Dies Reduced by Use of Gas Cutting and Welding*

By EVERETT CHAPMAN

✦Mr. Chapman is Director of Research and Engineering, Lukenweld, Inc.

IN DISCUSSING a particular application of the art of welding we are confronted with the limitation of having to talk in generalities in order that we may draw the broad picture. The application of gas cutting and welding to the fabrication of dies is no exception to this.

Heavy plates are available in thicknesses up to 16 in., and total weight as high as 55,000 lb. These plates may be cut to any desired profile or sketch by means of the oxyacetylene cutting torch. We then have immediately available as our primary building block the various odd shapes that are required by the die industry in a material which is two and one-half times as stiff as the material used heretofore, a homogeneous material which has no internal defects, which can be welded at an economical cost and whose price is that of rolling mill material.

Figure 1 shows a gas cut draw ring with its accompanying punch. With the large stocks of steel which are available at the commercial mills this punch and ring can be made ready for the machining operations in about 30 min.

The science of welding is dominated by the principle that one may put the required amount of material in exactly the right place, and these materials may vary in their compositions. We may, for instance, in building up a cutting die, use inexpensive low-carbon steel in the main body and, where a hard shearing edge is required, build up a deposit of hard alloy which may be ground to the required contour. Several alloys are available for this application whose Brinell hardness runs as high as 700. This operation is eminently cheaper than the old method of inserting hardened steel strips. It eliminates the machining operation and most of expensive hardened material which merely provides a sufficient body for the bolts which secure the strips to the die.

* Reprinted from *Automotive Industries*, Oct. 22, 1932.

Fig. 1—This Draw Ring and Punch Was Gas Cut from Single Piece

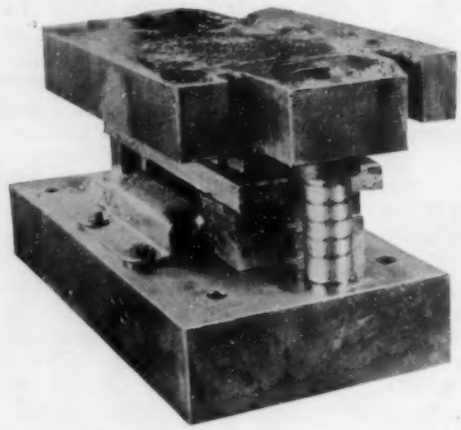


Fig. 2—Some Idea of What Can Be Accomplished with Gas Cut Plates in Line of Standardized Parts Is Seen Here

The small die set illustrated in Fig. 2 gives some idea of what can be done with gas cut plates in the line of standardized parts. This set consists of merely two plates cut to the proper contour and thick enough to provide a good body support for the guide pins.

The flexibility of the cutting torch combined with the welding operation is illustrated in the set of blank holders shown in Fig. 3. On these pieces the cutting has been done in two directions, the component parts being welded to form the completed blank holder.

Punch risers and necks are readily fabricated from plate by this new process as shown in Fig. 4. In the design of parts, such as these, the designer is freed of the limitations imposed by casting practice. The welding-minded designer will appreciate his freedom in being able to put a member immediately in back of a point of applied load without having to fill in a large hole to avoid the core cost. Well-designed dies in welded steel have actually shown a weight reduction of 65 per cent without sacrificing one bit the structural rigidity so essential to the production of accurate pieces.

With the duty on presses and dies mounting to meet heavier production demands, the superior rigidity of steel shows up beautifully in the increased accuracy made possible by the fact that the deflections may be reduced to a considerable degree. Thus, a simple bolster or reducing plate 10 in. thick will have only 40 per cent of the deflection of a cast-iron bolster 10 in. thick. We may turn this superior stiffness to account in another manner, namely, to reduce the amount of steel necessary to duplicate an already satisfactory performance. If our cast-iron bolster 10 in. thick was completely satisfactory we may substitute a steel bolster plate only $7\frac{1}{2}$ in. thick to get the same structural performance.

Figure 5 shows an example of a large cam-driven, side-acting die in which the base and driver supports are of welded steel, while the punch drivers are of cast iron. A combination of welded steel and simple castings will be the ultimate construction in the dies of the future. There are many places where the superior wear characteristics of cast iron under heavy pressure absolutely dictate its use, but the picture in no way suffers from this fact. Thus, for a large fender die the ideal combination will use a steel holder, in itself a guarantee against the breakage of such large expensive items, with the involved contours in cast iron.

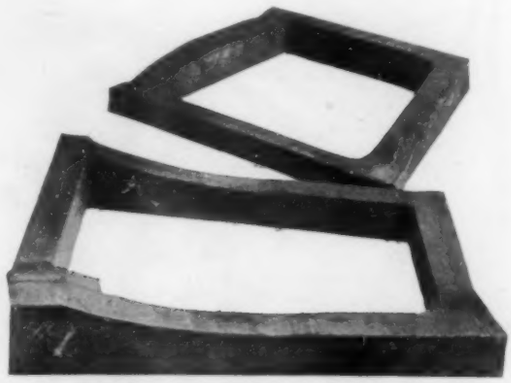


Fig. 3—The Flexibility of the Cutting Torch Combined with Welding Is Shown in This Set of Blank Holders

The salvage values contained in this whole picture are very attractive. Sufficient attention paid to the original design of die holders should allow of some interchangeability, and the very nature of the gas cutting process on sound steel plate insures that the reducer plates and bolsters may be used over and over again. There is no scrapping of castings or patching of the piece in the machining operation because of the presence of a large flaw at a critical point.

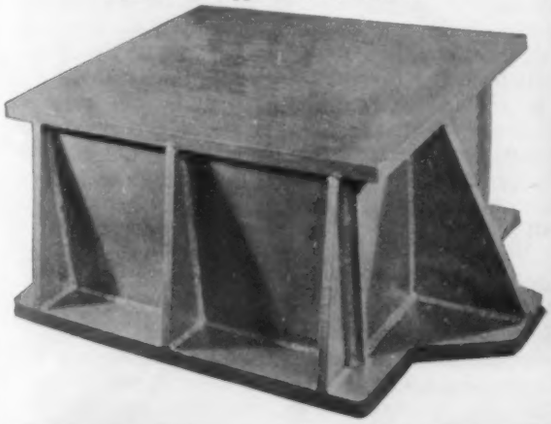
Figure 6 illustrates the use of a welded steel die-holder supporting a cast-iron contour piece. This large shell die shown in Fig. 7 has been fabricated from steel plate by cutting and welding at a cost of about 5 cents a pound and weighs about $^1/_3$ of the equivalent cast-iron die. This means that the process will compete with cast iron at $1^2/_3$ cents a pound. By equivalent, it is meant that this die will have the same deflection characteristic as the cast-iron die. The design view-point has been that the cast die heretofore used has been satisfactory. If the preceding design had not been satisfactory the necessary increase in stiffness can be incorporated at slight additional cost.

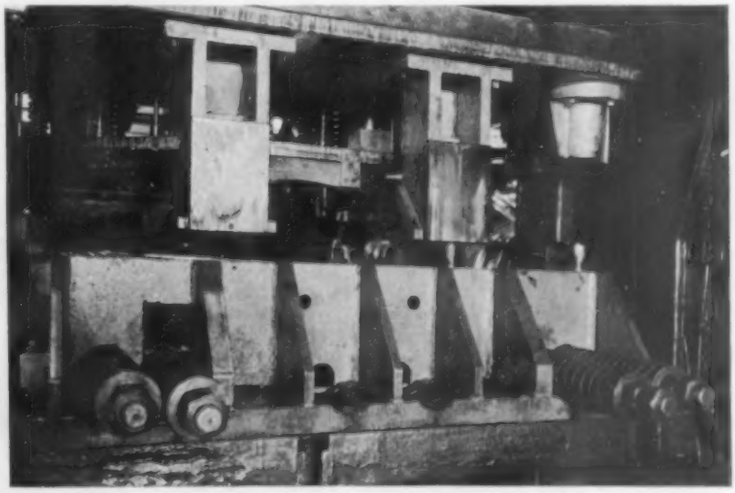
In addition to these obvious advantages from the cost and operating view-point there are several things that do not show up until the process has been thoroughly installed. In one large plant where many of these welded dies and bolster plates have been used, the lighter weight dies have reduced dangerous floor loadings to a comfortable point. The savings in the patterns which would have had to be bought, the saving in storage space for these same patterns and the insurance on the storage building have all accrued to the management who saw fit to initiate this revolutionary move.

The engineering department has to learn to think differently, more in terms of their function as engineers and less in terms of the foundrymen. The die shop will have to become acquainted with the production finishing of mild steel in contradistinction to the nicely machinable cast iron to which they are accustomed. Speed and feeds will change, as will the shapes of the tools. To compensate for this, there will be less actual metal to remove, no sand pockets to dull tools, no hard skin to plow under and no defects to pop up at the last minute.

Fig. 4—Below Is Shown Punch Risers and Necks Readily Fabricated from Plate by This New Process

Fig. 5—Right: This Large Cam-Driven Side-Acting Die Has Base and Driver Supports of Welded Steel





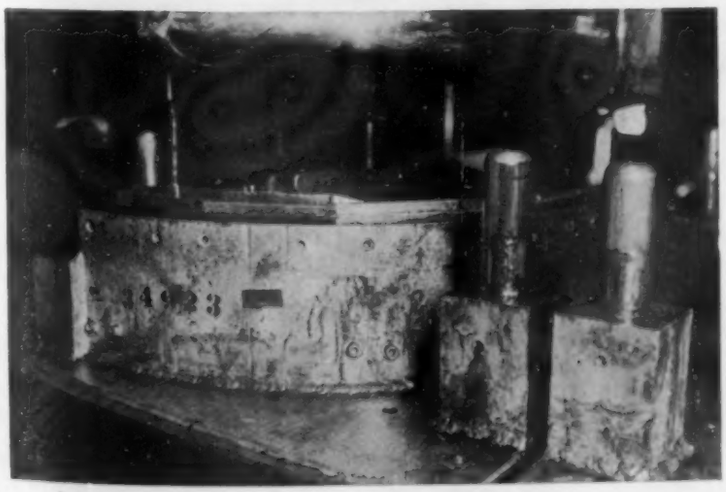
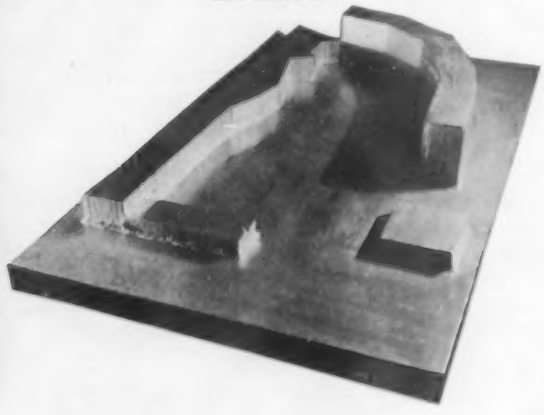


Fig. 6—Left: Here Is a Welded Steel Die-Holder Supporting a Cast-Iron Contour Piece

Fig. 7—Below Is Shown a Large Shell Die Fabricated from Steel at a Cost of 5 Cents a Pound and Weighing $^1/_3$ of the Equivalent Cast-Iron Die



HOW TO WELD IT

Boltless Connection for Welded Structures

By A. G. LEAKE

✦Mr. Leake is President of The Leake & Nelson Company.

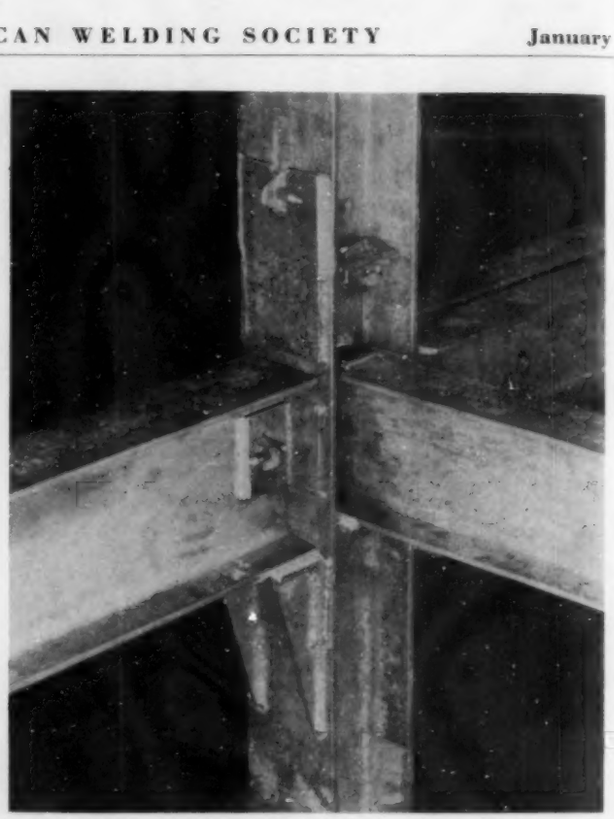
THE development of the use of welding in the erection of new structures has passed through the stage of question as to reliability and has reached a point where its use depends primarily on its economic advantages. The cost of a welded job as compared to a riveted job is the basis on which the future development of new welded structural work will depend. While on certain work in congested sections, adjacent to hospitals, and so forth, the elimination of the noise incident to riveting is a factor which would often justify the use of welding even at a slight additional cost, on the large majority of work the process used will be determined and is at present determined by actual dollars and cents involved.

Up to the present time it has been difficult to show actual savings on new construction when welding has been employed. This has not been due to any especially great expense in connection with the operation of welding as many savings result directly from its use. The number of men required for a given amount of work is less as compared to riveting, there is a material reduction in the scaffolding required and other minor economies prevail.

The point where economies have not previously been obtained in connection with welded structures, however, has been in the erecting, plumbing and guying of the steel and in the design of connections. Lacking better, connections similar to those which have been standardized for riveted work have been applied to welded work. With the different procedure they do not work out economically and the retention in welded work of the features of such connections, which are essential only to riveting, result in a much higher cost for the completed welded job than should obtain. To hold the steel in position for welding and to permit necessary plumbing, it has been necessary to field bolt the job very much as would be necessary for riveting. Holes must be shop punched in members and connections, and when the steel is erected, erection bolts must be inserted and tightened. These operations constitute a large part of the cost of steel erection, and inability in the past to eliminate them on a welded job has been a serious handicap to the furtherance of welding with its other advantages.

To meet this situation, I have recently devised a new method of connection for structural members in field welded work, by the use of which field bolting is eliminated and in addition a large part of the labor incident to plumbing and guying of the steel. Its use may readily, although not essentially, be extended to eliminate shop punching and riveting of structural members.

This connection,* which I have already made use of advantageously, consists fundamentally of (*a*) shop punched slotted connection fittings, welded or riveted to the supporting members, (*b*) small plate lugs, in each of which one hole is punched, welded to the connecting members at such location that they will fit into the slotted connections, and (*c*) a pin or drift to be driven into the hole in the lug. The assembly of this connection is shown in the photograph. When the steel is erected the lug fits readily into the slot and the member is held securely in place, ready for field welding by driving a pin through the hole in the lug, drawing the member to proper position and, to a large extent, eliminating all other plumbing.



New Connection Designed for Field Erection of Welded Structures

The joint is then welded and the lug burned off, if necessary, or in many structures it can be left in place.

The use of this method substitutes for the delay involved in inserting several bolts in a connection, fitting nuts to threads which are often battered and tightening the nuts, the operation of inserting a plain pin or drift in one thickness of metal and driving it home with a few light hammer blows. It eliminates the cost of erection bolts, substituting, therefore, the cost of a very small number of pins or drifts.

The method is flexible in its application and at the same time the connections themselves may readily be standardized. This makes it entirely feasible where desired to ship the structural members direct from the mill to the job without shop work of any kind, with the exception of milling of columns. A supply of connections can then be sent direct from stock to the job and welded to the members in the field in accordance with details furnished.

On the other hand, where conditions justify, all connections may be attached to the members in the shop either by riveting or welding as may be best suited to the particular shop involved.

The use of this method with its economies is by no means limited to the erection of new structures. Its use in the repair of existing structures is equally important.

* Patented.

In attaching reinforcing material to old members, new material of any width may be drawn into tight contact with the old material without making special and expensive clamps and without drilling holes in the old material for bolting. In applying additional stiffeners to old girders, it is frequently found that the webs of the girders are somewhat bowed. In a recent case where this method was used, new stiffeners were easily applied in close contact with the web of a girder seven feet deep, although the web was bowed one-half inch. The great value of this method, however, in the repair of existing structures, is in connection with the condition where welding itself is of greatest value, namely, where only a portion of a member is readily accessible for reinforcing. In such cases as webs of bridge girders where the greatest corrosion is at the level of a concrete deck in contact with one side of the web, the use of this method of securing the new material obviates the cost of removing and replacing concrete. It is similarly especially applicable in reinforcing floor beam flanges where masonry jack arches rest upon the bottom flange. While in these cases the plate itself is slotted, no loss of section need result as after the plate is welded in place the lug is burned off and the slot welded full, flush with the plate.

The availability of this method of reducing the cost of steel erection removes the most important stumbling block from the path of the development of welding in the erection of new structures and, by making welded construction definitely cheaper than riveted construction, clears the way for its increasing use with its incidental advantage of elimination of noise. Further, in its application to the repair of old structures, it permits the efficient application of new material at low cost.

Spot Welding the Rustless Steels

By **V. W. WHITMER**

✦Paper reprinted from Sept. 29, 1932 issue of the *Iron Age*. V. W. Whitmer is Metallurgist, Republic Steel Corp.

RUSTLESS steels are particularly well adapted to spot welding because of their clean surface, freedom from any oxide or scale and because of the absence of any coating such as zinc or lead, as on galvanized or terne plate stock.

Spot welding, in principle, is nothing more than holding two sheets in close contact between two copper electrodes about an inch or so in diameter with the contact ends tapered to about $^1/_8$ in. in diameter, and passing a current low in voltage but high in amperage through the circuit for a short period. Fusion immediately takes place between the two sheets, while the excess heat is rapidly carried away from the outside surfaces by the water-cooled electrodes. The low voltage, about 2 to 4 volts, is obtained from a step-down transformer wound in sections, each being connected with a stop on a rotary control switch by which the current or heat can be increased or decreased by turning up or down respectively.

Success Depends on Four Variables

While the total heat applied will be determined by the rotary adjustment, the area of the electrode points should be maintained as near constant as possible. Any increase in area will tend to reduce the heat per unit area, resulting in an improperly or poorly fused joint. A decrease in area will increase the unit heat and will usually burn a hole entirely or partly through the sheet to be welded, other factors remaining constant.

The pressure exerted by the electrodes is generally produced by the compression of helical springs and can be adjusted by a lock nut on a shaft through the center of the spring. Variable pressures will also affect the resistance of the joint and hence tend to decrease the quality of the weld. Too much pressure will reduce the heat generated. The pressure generally determines the amount of upset displacement directly following the fusing period, producing an indentation on each side of the sheets welded.

In addition to these variables, the time of current flow is of great importance. Too long a period gives the same result as too much heat. Too short a contact will produce no weld.

It is evident, therefore, that spot welding depends on the following four variables:

1. Current (controlled by rotary switch).
2. Diameter of electrode contact points.
3. Pressure (controlled by spring or pneumatic pressure).
4. Length of time the current is allowed to flow.

Less Heat Required for Rustless Steels

While it would not be impossible to determine an adjustment of each of these with respect to the other for each gage to be welded, as in the case of automatic machines where time and pressure are accurately controlled by motor-driven cams and the current set by hand, it would be next to impossible to determine them for manual operation, due to the personal element. Furthermore, such adjustment would be necessary for each individual machine. This makes it impossible to set up any specific procedure to follow for this class of work. However, rustless steel, such as Enduro, in general, will require less heat than the same gage in common steel, due to its lower heat conductivity (tending to concentrate it in one spot), its lower melting point and better contact due to a scale-free surface. Consequently, if an operator is producing good work on, say, 20-gage black steel, he could, in general, change to the same gage of rustless by either dropping the switch one point or reducing the time slightly, or both. More definite instructions cannot be given but the exact procedure must be worked out individually, balancing one variable against the other until the desired result is obtained.

Welds Should Be Placed in Inconspicuous Positions

If both electrodes are of the same diameter, a depression will occur on both sides which, while not serious on the pickle finishes, may be objectionable on the polished surfaces. This can be reduced by using a copper block about $^1/_2$ in. thick and 2 in. square between the electrode and polished side, thus putting the major depression on the lower side. An aluminum block $^1/_8$ in. to $^1/_4$ in. works even better, but due to its lower melting point will tend to pit if a slight arc is drawn. This procedure will reduce the depression but will not eliminate it entirely, as it is due to shrinkage of the molten metal in the center and, hence, pulls from both surfaces. The indentation remaining, if the work is to be polished, will have to be ground out with a cotton wheel set up with glue and abrasive. (Use about 80 grit or finer.)

When welding polished rustless steel, it is advisable to place the welds at the least conspicuous positions, as often it is difficult to refinish the welds and have the

same color if the whole piece is not refinished. This depends, however, to a great extent, upon the finish of the sheets.

Spot welding, like any other type of welding requiring high temperature, will form an oxide on the surface which will be blue in color. If this is exposed to the weather or moist conditions, it will slowly change to a brown color resembling rust. This, however, is only a surface condition, affecting the original oxide only. If such welds are to be exposed to the atmosphere, they should be cleaned either with acid, as in pickling in the case of No. 1 finish sheet, or ground and polished if No. 4 or higher finishes are employed. In the ground and polished state, spot welds are just as resistant to the salt spray as the original metal.

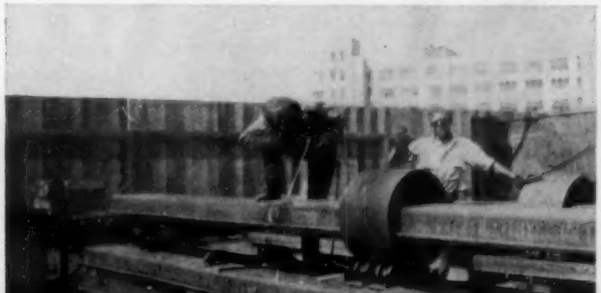
Position Finder Facilitates Welding of Heavy Piling

By **A. F. DAVIS**

✦Mr. Davis is Vice-President of The Lincoln Electric Company.

CONFRONTED with the task of butt welding heavy steel piling so as to form 50-ft. lengths, the Arc Welding Corporation of Los Angeles, California, devised a novel position finder which enabled the operators to do all welding in a horizontal position.

The piling was in the form of a heavy channel with a groove on each side so that each section would interlock with the next. Ten ft. lengths of piling were welded to 40 ft. lengths to form the required 50-ft. sections.



This Shop Constructed Position Finder Enables the Welding Operator and Helper to Handle Heavy Steel Sections by Hand and Keep the Work in a Horizontal Position

To facilitate handling and welding, a device was built which consisted of a section of 26-in. pipe approximately 18 in. long with a bar welded across the inside. The piling rested on the bar, practically in the center of the pipe. A jack was then placed on the other side of the piling and forced against the inside of the pipe. These position finders were used on both ends of the piling, being mounted on rolls similar to those used on pipe lines for making firing line welds. This enabled the operator and helper to turn the piling over by hand. While one section was being welded, the helper would set up another section.

Such a position finder could well be adapted to handle many long steel sections such as I-beams, angles, etc.

Welding was done by the shielded arc process. The piling was for the use of the Puget Sound Bridge and Dredging Co. and was delivered to them with all joints guaranteed.

Making Each Casting Good

By **DEWITT ENDICOTT**

✦Mr. Endicott is connected with the Technical Publicity Department of The Linde Air Products Company.

EVERY company that makes castings knows from experience that there are always a certain number of defective castings produced which under ordinary circumstances would have to be melted and recast. Not only is this sorting out of defective castings and reclaiming them by remelting costly, but it means that a higher unit cost has to be charged to each good casting. The use of the oxyacetylene process has effectively reduced the percentage of rejects to a minimum because of its ability to rectify defective spots and thus reclaim the castings without the need of scrapping.

A stove company in the East has found this to be particularly true with regard to the manufacture of gas ranges. For some time now it has been their regular practice to sort out all defective castings and send them directly to the reclamation department where all reclamation is handled by oxyacetylene cast-iron welding. A close look at the top side of a gas range frame that has been welded and ground smooth would show no evidence of a weld. Such excellence is the direct result of careful adherence to the recommended cast-iron welding procedure.

The illustration shows the back of such a casting and it will be noticed that the weld runs from top to bottom

Back View of Stove Casting Showing Unfinished Cast-Iron Weld

along the right-hand side. The white chalk mark has been drawn at the right edge of the weld along its entire length. The weld in this case has not been ground down or cleaned at all but this operation will be carried out before the stove is finally assembled.

The burners used on these ranges which were made up for a large foreign order were cast in two sections and then welded together with the cast-iron welding rod. The welds in every case are so smooth and clean that no machining whatever is necessary.

In welding gray cast iron with cast-iron welding rod, certain fundamental properties of gray iron must be thoroughly understood by the welder in order to insure successful results. To weld gray iron so the completed job will actually be gray iron throughout requires a definite procedure. This may be expressed briefly in the statement: Gray iron castings should be heated to a dull red before welding, welded while hot with high quality cast-iron welding rod and then cooled very slowly. The reasons for this procedure are quite apparent. Preheating the entire casting equalizes expansion and contraction stresses which might be sufficient to distort or crack the brittle metal if the heating was not uniform or properly controlled. Preheating is also necessary in order to facilitate the proper annealing of the casting, which is done by allowing the welded casting to cool very slowly, so that the carbon in the newly added weld metal will separate as graphite. Rapid cooling would result in weld metal consisting largely of white cast iron, which is extremely brittle and very difficult to machine. It is important that the casting be kept completely covered during the cooling to allow the temperature change to occur evenly throughout the piece. Following these precautions means that the weld will be soft and easily worked.

For such small castings preheating can be carried out by the blowpipe alone, but in routine reclamation work it is preferable to have a small preheating furnace so that a number of castings can be preheating while the welders are working on others. Before preheating the surfaces to be welded or filled in with cast iron are carefully cleaned with a stiff wire brush and, if edges are to be joined, beveled slightly by grinding. Welding is done with the blowpipe flame adjusted to neutral. Start at one end of the bottom of the depression or of the prepared vee and heat until the metal has melted to form a puddle. The tip of the inner cone should be $^1/_8$ to $^1/_4$ in. away from the metal.

It is highly important to remember that the use of high quality cast-iron welding rod and a good cast-iron flux is essential. When the base metal begins to melt and form a puddle, the end of the welding rod is heated in the flame and dipped into the cast-iron flux. It is then melted into the puddle. As the weld progresses, make certain that the edges of the base metal are thoroughly melted into the advancing puddle. In this way the defective portion of the casting or the parts to be joined are built up to the surface level, or slightly above the surface, if it is necessary to allow for finishing.

Whenever gas bubbles or white spots appear in the puddle or at the edges, flux should be added and the flame played around the section until the impurities float to the top, where they can be removed with the welding rod.

Welding should be continued without interruption until the weld is completed. The casting should then be permitted to cool very slowly and evenly. This can be done most effectively by having an annealing bin filled with dry slaked lime or asbestos paper torn into fine bits, in which the castings can be completely buried until stone cold.

When the cooling has been completed, the small castings can be easily machined or ground down and smoothed up as required.

It was precisely in this way that the reclamation of the gas stove castings and the joining together of the two-burner castings are accomplished. This, of course, is now regular production procedure and the management considers that their profitable operation is dependent to a large extent on their adoption of welding as a modern cast saving process.

A New Fabrication Job

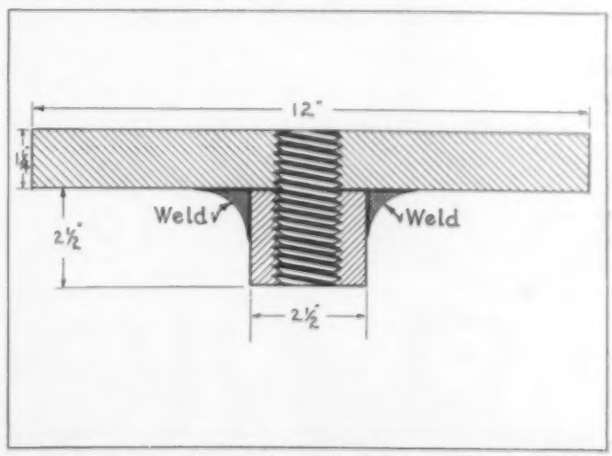
By DEWITT ENDICOTT

✦Mr. Endicott is connected with the Technical Publicity Department of The Linde Air Products Company.

DURING the manufacture of a large order of air-lock pump cylinders for use in connection with an air lock on vessels, is was found that the cast-iron cylinder head made for this type of pump required an improvement in design to fulfill its job satisfactorily. This head was about 12 in. in diameter and 1 in. thick, of circular shape, having a boss cast in the center of the head through which an adjusting screw worked. It was found that there was a tendency for the boss to fracture when the adjusting screw was tightened up and because of the close fitting tolerances of the part adjacent to the head it was impossible to reinforce this boss in any way.

As the order for these pumps was due to be completed in a very short time the situation, of course, caused the plant superintendent no little worry. It was obvious that redesign was imperative and, as the oxyacetylene welding process was used to a considerable extent in this plant for a variety of purposes, it was natural that the superintendent turned to this process to solve the problem for him.

A round piece of $1^1/_4$-in. steel plate was cut by means of the oxyacetylene cutting blowpipe to the exact size of the head. Then a short piece of shafting material was cut and centered on this head plate and, with the use of high-test steel welding rod, it was welded on to the plate. Then the plate was permitted to cool off and the whole head was put in a lathe, faced off and the hole drilled in the center and tapped to make the completed article. The whole job took less than $2^1/_2$ hr. for this first head, which proved to be in every way quite satisfactory for the work imposed on it. Consequently the procedure for manufacturing these heads has been completely changed from a casting process to an oxyacetylene welded fabrication process.



Sketch Showing Cross Section of the Redesigned Cylinder Head

FROM ABROAD

Welding of Steel Structures*

Chairman—Professor Sir H. C. HAROLD CARPENTER, Ph.D., F.R.S.

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E. S. ANDREWS, Esq., M.Inst.C.E., M.I.Struct.E.
A. F. BURSTALL, Esq., Ph.D.
F. R. FREEMAN, Esq., M.Inst.C.E.
G. A. HANKINS, Esq., D.Sc., A.R.C.S., A.M.I. Mech.E.
E. H. JONES, Esq.
J. H. PATERSON, Esq., D.Sc., F.I.C.
Professor A. J. S. PIPPARD, M.B.E., D.Sc., M.Inst.C.E., M.I.Mech.E.
H. B. WHITE, Esq.

THE question of welding is of great industrial importance in connection with the use of structural steel in building. Apart from matters of relative economy and efficiency, the demand for reduction of noise during construction is becoming more and more insistent. It would accordingly be of obvious advantage, both to industry and the public, if an authoritative pronouncement could be made on the efficacy of the welded joint in structural work, or if at least some indication could be given of the controls that require to be exercised.

The contributions from the industry and the facilities placed at its disposal by the Department, have enabled the Committee to embark on a series of investigations of the strength of welded joints under present British practice. Research into the technique of welding is beyond the scope of these activities.

Considerable attention has been given to the formulation of a program likely to lead to results in the near future. In the first instance, a review has been made of work on the subject that has been done, or is proceeding elsewhere in England and in other countries. A summary of the information collected is given in Part I of this Section.

In addition, a series of ad hoc tests has been carried out to clear up a number of salient points. A short note on these tests is given in Part II of this Section.

The program, as at present drawn, is outlined in Part III of this Section.

Part I—Review of Investigations into Welding

By G. N. BORROW

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Introduction

FUSION welding had been in use for many purposes for more than thirty years before 1917, when it was first applied on a large scale in America to the connections of heavy structural steelwork. The American firms interested in the expansion of the welding industry proceeded later to obtain essential design data as occasion required from experiments and full-size tests to destruction in their laboratories and shops. But before any general application of welding to heavy steel building frames could be expected it was soon realized that it was necessary to study the properties of welds and secure definite proof of their reliability under practical and commercial conditions.

In view of the obvious need of organized research, the AMERICAN WELDING SOCIETY,[1] acting through its research department, the American Bureau of Welding, in cooperation with the American Institute of Steel Construction, inaugurated an extensive series of tests designed to determine the ultimate strength of welded joints of types suitable for connecting structural members composed of standard rolled steel sections. These tests were carried out on small specimens in laboratories, testing shops and universities throughout the United States and Canada and a considerable amount of empirical data was acquired. The AMERICAN WELDING SOCIETY published in 1929 a recommended code of practice for structural welding,[2] which has already been incorporated into the building regulations of more than seventy large cities in the United States.

Organized research on similar lines has been carried out in most industrial countries, especially in Germany by the Association of German Engineers (Verein deutscher Ingenieure), the German Steelwork Association (Deutscher Stahlbau Verband) and the German Railway Company; in Switzerland by the Swiss Society of Boiler-owners (Schweizerischer Verein von Dampfkessel-Besitzern) and the Swiss Federal Railways; and in Belgium at Brussels University under the direction of Professor Dustin.[3] Regulations governing the application of welding to steel frame buildings have been issued by Polish[4] and Prussian[5] government departments, and by the city of Leipzig[5] and recommended codes of practice have been published by the Verein deutscher Ingenieure[5] and La Soudure Electrique Autogène of Brussels. Negotiations are in progress in Germany with a view to the establishment of a uniform code for the whole country.[5] This code has now been published.

Although structural welding is permitted by a number of authorities responsible for the safety of buildings, such permission is always qualified by the stipulation that the work shall be undertaken only by firms of recognized standing and carried out by welders whose efficiency is checked by periodical tests. Increased knowledge and the official recognition thus accorded resulted in considerable extension of the application of welding to structural work so that there are now in existence more than a hundred large all-welded steel frame buildings and several road and railway bridges in which the main connections are formed by welds. The use of welding in building construction is, however, still the exception, and its prohibition by the building regulations of New York and for buildings of more than one story by those of the London County Council seems to indicate some hesitation in responsible quarters to sanction the use in structural steelwork of a form of joint, the fundamental nature of which is not understood.

Types of Welds in Use

Three types of welds are used in heavy structural work, viz., butt welds, fillet welds and slot welds. In butt welds the weld metal is deposited in grooves of single or double V-section formed between the edges of two members or between the edge of one and surface of the other. In fillet welds the metal is deposited in the angle formed between two mutually perpendicular surfaces. The section of fillet welds is assumed for design purposes to be a right-angle isosceles triangle with

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the hypotenuse in the exposed surface of the weld. Fillet welds are distinguished as front or normal welds and as side or longitudinal welds accordingly as the load is applied, normal to or parallel to the length. In slot welds the metal is deposited in a groove of rectangular section formed by a slot cut through one and the surface of the other of two lapped members.

Butt welds have been studied at Zurich[3,6] in connection with boiler work, but their efficiency for large structural joints is still a matter for further consideration. They are more compact than fillet welds and afford a more direct transfer of stress, but they require greater care in design as the order in which they are made may materially affect the stress distribution in a structure, and the machining necessitated by their use may constitute an important item of cost. They are generally considered satisfactory in compression, but structural engineers are not in agreement as to their reliability in tension, in view of initial stresses set up during cooling. They should not, however, be condemned without further study on account of an occasional tendency toward non-uniform stress distribution as in some circumstances the full tensile or bending resistance of a member may be developed by their use when fillet welds could not possibly be made to fulfill the same purpose.

The strength of fillet welds was the subject of systematic research in 1926–1927 under Professor Dustin at Brussels University.[3] More than 200 tests to destruction were carried out under controlled conditions on front and side fillet welds. Front welds are subjected to stresses sensibly in one plane, suffer little deformation and fracture abruptly. The stress distribution was therefore investigated by Coker's photoelastic method. Side welds, on the other hand, undergo considerable elastic and plastic deformation before fracture so that the stress distribution could be examined by means of extensometers. It was found that tensile loads were transmitted by front welds as a tensile stress uniformly distributed over and normal to the plane of symmetry bisecting the right angle of the transverse section of the weld. Side welds were found to be subject to shear stress, acting in the plane of symmetry but the strength of the weld is not directly proportional to the area in this plane. When a tensile load is applied obliquely to a fillet weld the resultant stress partakes of the nature of both tension and shear and has not been precisely defined. When side and front fillet welds are combined in one joint the stress is not distributed among them in proportion to their individual strengths. Front welds take the larger proportion owing to their greater rigidity. This may be allowed for by reinforcing their section by 10–20 per cent. Other things being equal, front welds are stronger than side welds, but when used together, the front welds generally fail first, owing to the irregular stress distribution. These results were confirmed in a large measure by a similar investigation conducted during 1927–1928 at Toronto University.[7] It appears from these tests that the most important factor governing the strength of welded joints is the skill of the welder, and that eccentric loading is a potential cause of failure and should be avoided whenever possible.

Strength of Welded Joints

The structural welding codes and regulations so far published have been based on data obtained mainly from tests on small specimens and on such practical experience as was available and, although they mark a distinct step forward in structural welding practice, the need for further research is apparent. It has been definitely established that the specific strength of a welded joint depends not only on the quality of the weld metal and on the skill and integrity of the welder, but also on the dimensions of the weld, the direction of stress relative to the length of the weld and on the shape and size of the members joined. Data obtained from tests on small specimens carefully made under shop conditions should not, therefore, be directly applied to large welds made in the field possibly under severe conditions of exposure.

Tests to destruction on simple welded specimen joints have also been carried out in England on behalf of the Admiralty and Lloyds Registry of Shipping, and quite recently by F. R. Freeman[27] for Messrs. Dorman Long and Company. Freeman, describing these tests in a paper read before the Institution of Civil Engineers this year, states that the welds were made under shop conditions and points out that, as the stress distribution in a joint is much influenced by the relative elasticity and other physical properties of the weld and base metals, test records which contain no particulars of the electrodes used nor of the properties of the steel are of little value as a basis of design.

Tests on relatively small welded specimens, the stress distribution in which was simple and amenable to mathematical analysis, have served their purpose in establishing safe values of stress for use in design, in improving welding technique and in developing methods of supervision and inspection, but they afford no information on the behavior of welds forming joints in large steel structures and subject to complex stresses which cannot be exactly determined. Uncertainty as to the behavior of welds in such circumstances is reflected in the large differences observable in the accompanying Table 1, between the stress values permitted by various codes and regulations.

The knowledge required can be obtained only from tests to destruction on full-size structures. Investigations of this nature have been undertaken in several countries for the solution of specific problems.

An extensive investigation of welded steel structures was planned by the American Bureau of Welding in 1926 to secure fundamental design data.[8] A plate

Table 1—Permissible Stress* in Welded Joints under Various Regulations

	Authority	Specified	Tons per Sq. In.
Tension	Am. Weld. Soc.	13,000 lb./sq. in.	5.7
	San Francisco	.....	..
	Ver. deuts. Ing.	850 kg./cm.^{2}	5.39
	Prussia	720 kg./cm.^{2}	4.57
	Leipzig	600 kg./cm.^{2}	3.81
Compression	Am. Weld. Soc.	15,000 lb./sq. in.	6.7
	San Francisco	6,000 lb./sq. in.	2.68
	Ver. deuts. Ing.	1,100 kg./cm.^{2}	6.98
	Prussia	900 kg./cm.^{2}	5.71
	Leipzig	600 kg./cm.^{2}	3.81
Shear	Am. Weld. Soc.	11,300 lb./sq. in.	5.05
	San Francisco	6,000 lb./sq. in.	2.68
	Ver. deuts. Ing.	750 kg./cm.^{2}	4.76
	Prussia	600 kg./cm.^{2}	3.81
	Leipzig	500 kg./cm.^{2}	3.17
Flexure	Am. Weld. Soc.	Maximum fibre stresses must not exceed those specified for tension and compression respectively.	
	Ver. deuts. Ing.	850 kg./cm.^{2}	5.39
	Prussia	As for tension and compression respectively.	
	Leipzig	600 kg./cm.^{2}	3.81

* Measured on the area $l \times h$, in which l is the length of the weld exclusive of end craters and h is, for fillet welds, the minimum distance from root to hypotenuse of largest isosceles triangle in cross section of weld and, for butt welds, the thickness of the thinner part joined.

girder, 15 ft. long with a 2-ft. web 1/2 in. thick, cover plates 9 1/2 in. wide and nine stiffeners on each side welded to the web and the flanges, was tested to destruction. The welds failed at the top flange but only after the web had buckled and the deflection of the girder had amounted to several inches.

The strength of welded shelf angle connections for beams to columns of types suitable for use in steel frame buildings has been investigated by means of a series of tests at the U. S. Bureau of Standards[9] in which special attention was directed to the effect of changing the dimensions of the shelf angles and of the positions of the welds with respect to the angles. The columns were of I-section and all the connections were made by means of fillet welds round the periphery of the shelf angles. All failures occurred in the welds and there was no definite indication that variations in the width of the vertical flange, the thickness or the length of the angles had any effect on the strength of the joint.

Another series of tests carried out by the Bureau of Standards[10] was designed to determine the effect of substituting welds for rivets in the splices of I-columns of steel building frames and of placing the splice plates parallel to the webs instead of to the flanges. The strength of welded splice connections of H-sections was also studied but the tests did not include the determination of the shear strength of such connections. Several welded seams failed under a calculated stress of 14,100 lb./lin. in. due to a concentration of stress at the ends of the welds, but in no case did failure begin in a weld. It was concluded that welds designed in accordance with the AMERICAN WELDING SOCIETY'S code have adequate strength.

The rigidity of welded beam to column connections has been studied by means of tests at Lehigh University[11] and in the shops of the Westinghouse Electric and Manufacturing Company.[11] In the Lehigh tests 8-in. I-columns were used. It was found that high stresses were developed in the weld under working loads, when the web of the beam was welded to the column and the factor of safety indicated by such web welded connections was not considered high enough for practice. The stresses in the weld were, however, reduced when the lower flange of the beam was in contact with the column and the rigidity of the joint was increased. Flange welded joints were practically rigid, so that full negative moments should be used in their design. In the Westinghouse tests, double cantilever beams were welded one on each side of the column so as to make symmetrical specimens and produce the effect of beams connected to a rigid column. Four types of joints were used. It was concluded from these tests that when angles are used in connections to produce flexibility, welds should not be placed on the sides of the flexible leg of the angle and that, although connections formed by welding the web of the beam to the column may be satisfactory under static conditions, they should not be used to transmit dynamic stresses.

Tests on full-size welded open web I- and box beams and on lattice columns have been carried out at the University of California, Berkeley.[12] The box beams all failed through buckling of the diagonals in compression and the I-beams which were supported to prevent twisting by buckling of the angles forming the upper flange. The columns all failed through buckling of the legs between the latticing and in no case of beams or columns was any weld damaged although the welding had been done by inexperienced workers. Investigations on welded structures conducted for the German Railway Company acting in cooperation with the German Steelwork Association (Deutscher Stahlbau Verband) included comparative tests on riveted and welded girders of 9 m. span, built up of the ordinary commercial sections and of tubular members.[13] It has been reported that the ultimate strength obtained justifies the adoption for such structures of a permissible shear stress of 570 kg./cm.^{2} (8107 lb./sq. in.). Tests on thirty welded structures are in progress at the Dresden testing station (Materialprüfungsamt, Dresden) on behalf of the German Railway Company and the Steelwork Association, the results of which will be published in Stahlbau.[14] Experimental evidence of the efficiency of electric arc welding for heavy structural work has also been supplied by tests carried out by the London and North-Eastern Railway in connection with the strengthening of bridges. Specimens were obtained by cutting a 14- by 6-in. steel joist into two equal lengths. One was left intact and the other was sawed down the neutral axis and the lower flange was cut, the cuts being subsequently joined by welds. When tested to destruction under transverse loads the welded specimen was found to be the stronger.

The behavior of welds when used in conjunction with rivets which attained importance through the use of welding for strengthening existing railway bridges has been studied at the Federal testing station, Zurich, on behalf of the Swiss Federal Railways.[15] The use of welding was found to be justified in that it was established that the stress in the rivets was relieved at any rate so long as the loads permitted in practice were not exceeded.

The behavior of welded joints under the prolonged action of dynamic forces has lately attracted the attention of investigators on account of the increased use of welding in the construction of steel frame buildings and especially of road and railway bridges and other structures subject to repeated stress. Research on the fatigue strength of fillet welds is in progress in the laboratories of the Westinghouse Electric and Manufacturing Company,[16] the results of which so far available cover work on the effects of machining, spacing and size of the weld. Tests carried out on rotating cantilever specimens 1 in. in diameter indicated the existence of a limiting size of weld below which failure occurs in the weld and above which in the parent metal. In the former case failure begins in the interior of the weld. It was found also that the fatigue strength is not materially increased by machining a radius at the base of the weld and was considerably lowered when the parts to be joined were not in contact.

Fatigue tests have been conducted by the German Railway Company on welded and on riveted trusses for the purpose of comparing the behavior of the two types under dynamic loading and to obtain data for the development of a method of judging the condition of existing bridges by observation of their vibration.[17] The trusses were mounted on a testing stand and stressed under conditions approaching as nearly as possible those obtaining in service. Both the German and the Swiss Railways[18] have experimental welded bridge trusses built into their tracks, with necessary precautions to prevent accident and under scientific observation while subjected to the stresses of normal railway service. The fatigue strength of welded joints was included in the research program carried out by Lloyd's Registry of Shipping to obtain data on which to base regulations governing the use of welding in ship construction.

Field Test for Soundness of Welded Joints

Perhaps the greatest obstacle to the general application of welding to building construction is the impossi-

bility at the present stage of development of guaranteeing the soundness of all the welds in a large structure. The metal deposited by the electric arc process is by no means uniform in strength. Cavities and slag inclusions frequently occur and the degree of penetration may be very irregular. The extent to which these defects occur and the variation in strength associated with them may be said to depend not only on the experience and good-will of the welder but also on his physical and mental condition on some particular occasion. This difficulty is met as far as possible by careful selection, training and supervision of welding personnel but can be eliminated only by the development of some simple non-destructive test easily applicable at any part of lofty skeleton structures.

The development of non-destructive tests has attracted the attention of many investigators in England, America, Germany and Belgium and considerable progress has been achieved with processes based on magnetic and electric methods of exploring the interior structure of welds and on examination by means of X-ray photography.

A magnetic method of testing welds has been developed by Roux in the laboratories of La Soudure Autogène Française. A magnetic flux is passed by means of an electromagnet across the weld and differences in the magnetic potential resulting from faults or failures in the homogeneous character of the weld metal are made apparent by spectrographs obtained by sifting iron filings on a sheet of paper placed over the weld. This method is valuable for laboratory use for the examination of butt welds, but is not sensitive enough to reveal any but serious faults when applied to the rough surface presented by welds in ordinary practice, and attempts to apply it to fillet welds have not been successful.[19] An improved magnetic method, in which the field is explored by means of a search coil in circuit with a galvanometer, has been introduced at Brunswick Technische Hochschule.[20] A further development consists in the use of a transformer, the secondary coil of which is replaced by the weld under examination. This method is still in the experimental stage and, although it may be useful for examining butt welds, its application to fillet welds is improbable. An experimental magnetic tester for comparing the qualities of welded joints on ships' plates was constructed at the National Physical Laboratory on behalf of the Admiralty in 1925, and the results obtained were considered sufficiently promising to warrant further investigation. Experiments with alternating currents were also made, but this method was abandoned. Attempts to obtain results with the tester on lapped joints were unsuccessful and the trial seemed to indicate that the application of magnetic methods to the examination of such joints would be very difficult.

An electrical method based on the observation of irregularities in the resistance to electric currents passed across the weld was described by E. A. Sperry at the 9th annual meeting of the AMERICAN WELDING SOCIETY.[21] Apparatus identical in principle with that used for the detection of transverse fissures in railway tracks has been adapted to the examination of welds. The results obtained with a series of test specimens were in close agreement with those of subsequent tests to destruction. It is stated that thicknesses of steel up to 4 in. can be examined. Special inspection elements are necessary for structural shapes, but can be easily provided. Apparatus suitable for testing welds in steel building frames during erection consists of a small plant about the size of a 5-kw. welding set. It is claimed that with this plant, slung from a crane, the course of the welding can be followed and an ink record of the soundness of the welds be made as the work proceeds.

In the earlier attempts to examine the internal structure of welds by means of X-rays the rays were passed only in a direction normal to the plane of the specimen and the photographs so obtained, while giving some indication of the presence or absence of cavities, cracks or other irregularities in the metal, afforded no information as to possible lack of fusion especially on the scarfs of V-welds. An improved method has been developed in the Union Carbide and Carbon research laboratories[21] in which this defect has been overcome and lack of fusion is clearly indicated by taking three photographs in directions parallel to each scarf and normal to the weld, respectively. It is claimed that when the physical properties of the steel and of the welding metal are known the ultimate strength of the weld may be estimated with considerable accuracy from the appearance of the photographs.

Methods of examining welds by means of X-rays have been developed in the research laboratories of the German Railway Company at Wittenberg and tests in connection therewith have been carried out at the Kaiser Wilhelm Institute for Metal Research (K. W. Institut für Metallforschung) at Dahlem. Specimens containing, respectively, the more common defects occurring in practice and others as nearly perfect as possible were examined by X-ray and metallographic methods and were subjected to mechanical tests, so that characteristic X-ray photographs could be correlated with the mechanical properties of the welds.[20] The German Railway Company has in service an X-ray testing plant and it is stated that after a little experience inspectors can easily obtain with it reliable information as to the quality of the weld. The Swiss Federal Railways also employ the X-ray method for acceptance tests for welded steel bridges. The application of X-rays to the examination of welds has been studied also at the National Physical Laboratory and the Research Department, Woolwich.

Although the processes referred to are of undoubted value in the laboratory for the detection of faults in specimen welds with a view to tracing their causes and so developing an improved technique, the somewhat extravagant claims put forward by some investigators require qualification. Visual inspection still remains the only practical means of judging the soundness of structural welds in building frames.

Properties of Welds

Apart from mechanical tests, a considerable amount of research work has been devoted to the study of the fundamental properties of welds and of the reactions involved in the welding process. The importance of the welding rod or electrode has been clearly demonstrated by Dustin's researches at Brussels University. The question as to whether bare or coated electrodes are preferable has not been conclusively answered. In America and Germany the bare electrode is more generally used, while in Switzerland, Italy and Belgium the coated is preferred.

In the earlier applications of electric arc welding to steel structures direct current was generally employed, on account of the difficulty of directing the flow of metal with alternating current, but this difficulty has been eliminated by the introduction of coated electrodes and recently in Germany by a bare electrode of special physical constitution which exerts a directive force on

the molten metal analogous to that of the coated electrode.[22] The functions of the coating are to produce an ionizing effect which reduces the striking voltage and to protect the molten metal from oxidation and combination with atmospheric nitrogen by means of the slag which also forms a vehicle for the introduction of various elements into the weld metal for the purpose of modifying its properties as desired. Dustin concludes from his investigations that the best electrodes are those which deposit metal having mechanical properties as nearly as possible identical with those of the parent metal and recommends for structural work an ultimate strength of about 40 kg./mm. and an elongation of about 20 per cent. An elongation of 25 per cent would be more in accordance with structural steel, but its specification would mean the rejection of many reasonably priced electrodes which have proved efficient in practice. The elongation referred to is measured on a gage length of 10 diameters.[22]

A tentative specification for welding electrodes was published in 1926 by the Society of German Engineers (Verein deutscher Ingenieure) and a revised edition is now being considered by the Society's welding committee. The results of 10 years' research in the laboratories of the I. G. Farbenindustrie A.-G. have been summarized in a recent handbook issued by the company.

Researches conducted in the laboratories of Böhler Brothers and Company to investigate the effect of nitrogen[23] on welds made with bare and coated electrodes and with commercial welding wires indicated that nitrogen exerted little effect on welds made with high class electrodes, but that ordinary welding wire should not be used for arc welding. The ductility of the weld metal is of great importance in structural welding, but it is stated that the ductility of weld metal specimens varies so much with the skill of the welder that it affords no criterion of the intrinsic properties of the electrode.

The phenomena associated with the transference of the molten metal from the electrode to the weld have been examined at the Berlin Technische Hochschule by a kinematograph method taking 4000 pictures per second.[24] Systematic research in this field is being undertaken by the welding committee of the Society of German Engineers in order to determine the best voltage and current strength for various electrodes. The Society is also investigating the effect of penetration on the efficiency of welds and the factors on which the depth of penetration depends. Distortion and temperature stresses in the parent metal due to the heat developed by welding have been studied at Wilhelmshaven and it has been suggested that when sufficient studies of the magnitude, direction and distribution of such initial stresses have been made, the order in which the welds are made in a structure might be so controlled as to enable the engineer to reduce the dimensions of some members in which the initial stresses were opposed to the loading stress. It must, however, be first established that such initial stresses persist.[25]

A program drawn up by the Fundamental Research Committee of the AMERICAN WELDING SOCIETY[26] embraces many phases of welding and includes such problems as the relation of ductility to other mechanical properties of welded joints, impact resistance of welded joints; effect of method of making arc and gas welds on their ductility; transference of metal from electrode to weld; X-ray study of crystal structure of welds; investigation of fatigue strength of welded joints; comparison of welds made with bare and coated electrodes respectively; calorimetric studies of carbon and metal arcs; comparative merits of various types of joints on minimizing welding strains; the effect of paint and galvanizing on weldability; tests on various types of beam to column connections; effect of speed of welding and current strength; advantages and disadvantages of deep penetration; non-destructive tests; effect of size and shape of fillet welds on their strength; and temperature studies of direct and alternating current iron arcs in air and other gases.

References

[1] "Work of the American Welding Society," JOURNAL OF THE AMERICAN WELDING SOCIETY, **6**, [10], 6 (1927).

[2] F. P. McKibben. "Provisions of Welding Society Code for Structural Welding," *Engineering News-Record*, **103**, 92–93 (1929).

[3] H. Dustin. "The Design Calculations for Welded Joints in Structural Steelwork," *Génie Civil*, **94**, [14], 330–332 (1929).

[4] S. Bryla. "The Application of Electric Welding to Steel Construction," *Zeitschrift des Oesterreichischen Ingenieur-und Architekten-Vereines*, **80**, [37/38], 328–333 (1928).

[5] F. Bohny. "The Welding of Steel Buildings and Bridges," *Bauingenieur*, **11**, [49], 680–681 (1930).

[6] A. Bühler. "Electric Welding Applied to Steel Structures in Switzerland," Paper presented at Liège Congress on Metallic Structures, **1930**.

[7] P. Gillespie. "Structural Welding Experimental Study," *Canadian Engineer*, **56**, [3], 143–146 (1929).

[8] United States Bureau of Standards, *Technical News Bulletin*, **1926**, 113.

[9] J. H. Edwards, H. L. Whittemore and A. H. Stang. "Strength of Welded Shelf Angle Connections," *Bureau of Standards, Journal of Research*, **5**, [4], 781–792 (1930).

[10] J. H. Edwards, H. L. Whittemore, and A. H. Stang. "Transverse Tests of H-Section Column Splices," *Bureau of Standards, Journal of Research*, **4**, [3], 395–413.

[11] Beam Connection Tests Discussed at Welding Meeting; Annual Convention of AMERICAN WELDING SOCIETY, April 1930; Structural Steel Welding Committee Report. *Engineering News-Record*, **104**, [18], 727–728 (1930).

[12] B. M. Shimkin. "Laboratory Tests on Arc-Welded Latticed Steel Columns," *Engineering News-Record*, **102**, 879–880 (1929).

[13] Schaper, "Structural Welding," *Bautechnik*, **8**, [6], 73–74 (1930).

[14] H. Schmückler, "Progress in Structural Steel Welding," *Zeitschrift des Vereins deutscher Ingenieure*, **74**, [46], 1573–1579 (1930).

[15] A. Bühler, "The Swiss Federal Railways' Tests on Welded and Riveted Joints," *Stahlbau*, **3**, [20], 229–234 (1930).

[16] R. E. Petersen and C. H. Jennings, "Fatigue Tests of Fillet Welds." Paper presented at 33rd Annual Meeting of the American Society for Testing Materials, June 1930. Abstract in *Engineering*, **130**, [3372], 281 (1930).

[17] R. Bernhard, "Fatigue Tests on Riveted and Welded Bridges," *Zeitschrift des Vereins deutscher Ingenieure*, **73**, [47], 1675–1680 (1929).

[18] Beguin, "All Arc-Welded Experimental Bridges on the Federal Railway," *Bulletin technique de la Suisse Romande*, **56**, [4], 45–47 (1930).

[19] T. R. Watts, "Magnetic Testing of Butt Welds," JOURNAL OF THE AMERICAN WELDING SOCIETY, **9**, [9], 49–68 (1930); *Welding Engineer*, **15**, [10], 31–35 (1930).

[20] ——, "Testing Welds," *Zeitschrift des Vereins deutscher Ingenieure*, **74**, [32], 1125–1126 (1930).

[21] "Welding Society Considers Methods of Testing Welds at 9th Annual Meeting," *Engineering News-Record*, **103**, [12], 463–466 (1929).

[22] H. Dustin, "Riveted and Welded Joints." Paper presented at Liège Congress on Metallic Structures, September 1930.

[23] J. Fuchs, "The Influence of Nitrogen in Electric Arc Welding," *Zeitschrift des Vereins deutscher Ingenieure*, **74**, [46], 1569–1572 (1930).

[24] A. Hilpert, "The Transference of Metal in Electric Arc Welding," *Zeitschrift des Vereins deutscher Ingenieure*, **73**, [23], 798–799 (1929).

[25] Lottmann, "The Consideration of Temperature Stresses in Arc Welding," *Zeitschrift des Vereins deutscher Ingenieure*, **74**, [38], 1340–1345 (1930); [46], 1560.

[26] "Fundamental Research in Welding Field," JOURNAL OF THE AMERICAN WELDING SOCIETY, **1**, [9], 7 (1930).

[27] F. R. Freeman, "The Strength of Arc-Welded Joints," *Engineering*, **131**, [3395], 192 (1931).

Part II—Tests on Selected Specimens

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These tests, which were carried out at Messrs. Kirkaldy's on January 14, 1931, consisted of two series, prepared by two members of the Steel Structures Research Committee.

The first series was prepared by Dr. Burstall, in order to compare the strength of welded fillets with similar fillets of solid steel, and to investigate the question of the existence of adhesion of the parent metal at the apex of the fillet. Some of the specimens were made with covered electrodes, and these were duplicated by others made with bare-wire electrodes in order to compare the quality of the welds made by the two types. The type of specimen used consisted of two 2-in. x $^{7}/_{8}$-in. bars, lap welded by two $^{3}/_{8}$-in. tension fillets. Similar specimens cut from the solid were made and,

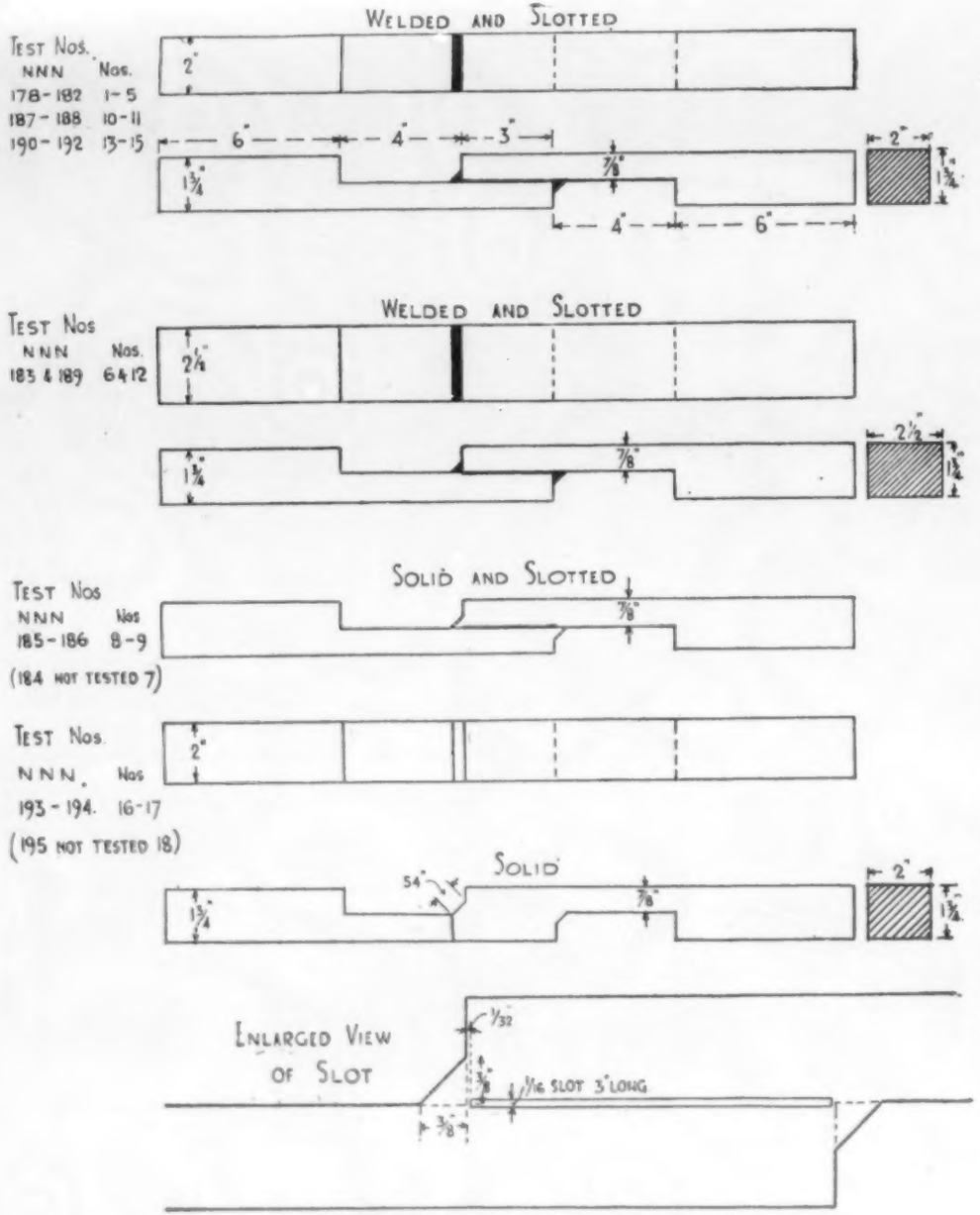

Fig. 1—Sketch of Special Welded Steel Specimens

Test No.	Description	Dimensions Size	Dimensions Welded Joint	Total Load Yield	Total Load Ultimate	Extension in 8 inches including Weld One Side	Extension in 8 inches including Weld Other Side	Appearance of Fracture and Remarks.
NNN	See Sketches for Sizes and other details No.	Inches		Lb Tons	Lb Tons	%	%	Welded Specimens all broke at Weld
178	2"×⅞" welded and slotted Weld Machined. 1	2·00×·86	·26 ·28 / ·28 ·27	48,800 = 21·8	72,500 = 32·4	2·7	2·7	Silky, small blow holes at root of weld
179	Do. Weld NOT Machined 2	2·00×·87	·20 ·26 / ·26 ·27	48,900 = 21·8	73,500 = 32·8	2·6	2·6	Do. very small cavity at root of weld one end, other end Silky
180	Do Weld Machined. 3	2·00×·86	·28 ·27 / ·28 ·27	50,000 = 22·3	60,800 = 27·1	2·2	2·2	Silky, each end
181	Do. Weld Machined. 4	2·00×·87	·27 ·28 / ·27 ·28	44,440 = 19·8	44,440 = 19·8	1·6	1·6	Silky dirt inclusion at root of weld each end
182	Do. Weld NOT Machined 5	2·00×·87	·28 ·27 / ·27 ·26	55,300 = 24·7	74,280 = 33·1	2·5	2·5	Silky, not welded at root, other end Silky
183	2½"×⅞" Welded and Slotted. Weld NOT Machined 6	2·48×·87	·25 ·27 / ·25 ·24	63,800 = 28·1	88,000 = 39·3	2·5	2·5	One end Silky. Other end ⅘ Silky ⅕ Crystalline.
184	NOT TESTED 7	—	—	—	—	—	—	———
185	2"×⅞" Solid & Slotted 8	2·00×·88	·30 ·28 / ·26 ·28	35,400 = 15·8	74,600 = 33·4	3·1	3·1	Silky, Crystalline speck one end. Silky other.
186	2"×⅞" — Do. — 9	2·00×·89	·28 ·26 / ·28 ·28	40,800 = 18·2	71,000 = 31·7	3·1	3·1	Silky, each end
187	2"×⅞" Welded & Slotted Weld Machined. 10	2·00×·87	·27 ·27 / ·28 ·28	59,900 = 26·7	66,300 = 26·9	1·5	1·5	Silky. Porous and Dirt inclusion each end.
188	2"×⅞" Do. 11 Weld NOT Machined	2·00×·87	·24 ·28 / ·27 ·26	50,800 = 22·7	68,400 = 30·5	1·9	1·9	Silky one end; other end porous at root of welds ⅞" Silky ⅛ Crystalline.
189	2½"×⅞" Do. 12 Weld NOT Machined	2·48×·86	·30 ·23 / ·40 ·20	68,300 = 30·5	93,500 = 41·7	2·2	2·2	Crystalline, some blow holes each end
190	2"×⅞" Do. 13 Weld Machined	2·00×·87	·27 ·27 / ·28 ·27	54,300 = 24·2	69,500 = 30·9	1·7	1·7	½ Silky, ½ Crystalline one end; other end Silky, some blow holes.
191	2"×⅞" Do 14 Weld Machined	2·00×·86	·27 ·27 / ·27 ·28	46,500 = 20·8	60,000 = 26·8	1·6	1·6	Silky Crystalline trace one end; Crystalline with Silky trace other.
192	2"×⅞" Do. 15 Weld Machined	2·00×·87	·26 ·27 / ·27 ·26	49,100 = 21·9	49,100 = 21·9	1·4	1·4	½ Crystalline ½ Silky one end; other end Silky, Crystalline trace
193	2·00×⅞ Solid. 16 (No Slot)	2·00×·88	Fillet See Sketch	40,500 = 18·1	101,900 = 45·5	4·1	4·1	Crystalline, broke at root of triangle
194	2·00×⅞ Do. 17	2·00×·88	Do	41,600 = 18·6	106,000 = 47·3	4·6	4·6	Do Do
195	Not tested 18 Turned Specimen cut from this Bar.	—	—	—	—	—	—	———

Covered Electrode

Bare Wire Electrode

Table 2—Results of Tests of Special Welded Specimens

in order to leave fillets of solid metal, $^1/_{16}$-in. slots were cut through the solid in the part corresponding to the lap in the welded specimens. The welded specimens had similar slots cut so that the conditions under test might be identical. The question of adhesion was studied by having the slots in two of the welded specimens somewhat shorter, thus leaving any adhesion which might be present. The results of the tests are given in Table 2 and sketches of the specimens in Fig. 1.

The second series was prepared by Mr. Jones. Reference is made elsewhere to the statistical examination which is to constitute the main program of research. A drawing giving the various types of specimens to be used in this examination had already been prepared, modeled to some extent on the specimens used in the similar research being carried out in America. When the results of the tests carried out by Mr. Freeman for Messrs. Dorman Long and Company were made available, the proposed types of specimens were revised as it seemed probable that some at least might break in the plates and not at the weld at all. A set of the revised specimens was then prepared and tested in order to make sure that all would fail in the weld before the main program was entered upon.

The results of the tests are given in Table 3 and sketches of the specimens in Fig. 2.

Four of the specimens broke in the solid. Three of these are easily explained, the other is not. It was found during the tests that a very mild steel of 24 tons per sq. in. ultimate strength had been used in making up the specimens, instead of steel of structural quality. Three of the specimens were butt welded and heavily reinforced on both sides, and the joint was stronger than the plate.

The fourth specimen, which was estimated to fail at 120 tons, broke through the solid, some distance away from the weld at 84 tons, or about 14 tons per sq. in. The specimen had a history; to begin with the plates of which it was composed, $^7/_8$ in. and $^3/_4$ in. thick, had been sheared along the edges, and secondly in putting the specimen weighing some 56 lb. into the machine it was allowed to drop 4 ft. onto a rail at the base of the machine.

Dr. Gulliver, of Messrs. Kirkaldy's, puts forward the suggestion that this treatment may have been sufficient to start a fine crack at the point of impact, resulting in the plate tearing across.

A standard tension specimen was cut from the plate which failed, and when tested broke at 24 tons per sq. in.

In order to discover whether any change in the microstructure of the plate had been caused by the heat of welding, an examination of the specimen was made by Professor Sir Harold Carpenter. But as the plate was made from very mild steel, probably about 0.06 per cent carbon and, since the structure of steels of this type

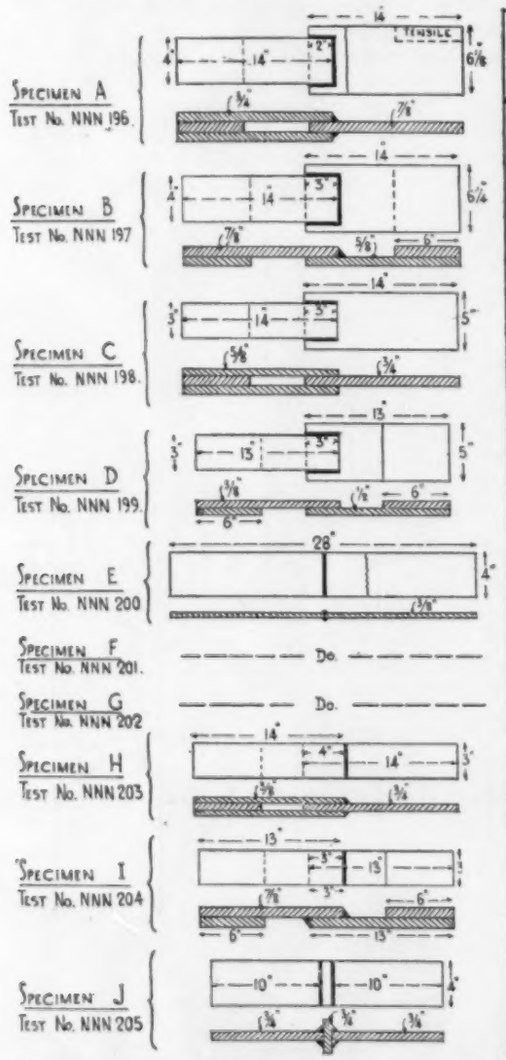

Fig. 2—Sketch of Selected Welded Steel Specimens *A* to *J*

Test No.	Description	Dimensions		Yield		Ultimate Total Load	Remarks
		Size	Welded Joint	Weld	Solid		
NNN	See Sketches for Sizes and Other Details	Inches	Inches	Lb Tons	Lb Tons	Lb Tons	
196	Double Weld (Lap) A	6·03 x ·96 4·04 x ·75	2·02 x 4·04	——	184,200 = 82·1	188,100 = 84·0	Broke in Solid, Crystalline (6" Plate)
197	Single (Lap) B	6·00 x ·62 4·02 x ·85	3·02 x 4·02	110,800 = 49·5	130,000 = 58·0	130,700 = 58·3	Broke at Weld
198	Double C	5·04 x ·75 3·02 x ·61	3·06 — 2·10	123,000 = 54·9	132,500 = 59·2	149,600 = 66·9	Broke at Weld
199	Double D	5·00 x ·50 3·07 x ·62	3·08 3·10 —	61,000 = 27·2	68,400 = 30·5	70,700 = 31·6	Broke at Weld
200	Butt Weld E	4·00 x ·38	——	——	55,500 = 24·8	80,600 = 36·0	Broke in Solid. Silky.
201	Butt F	4·00 x ·36	——	72,200 = 32·2	52,600 = 23·5	76,600 = 34·2	Broke in Solid Do.
202	Butt G	4·02 x ·37	——	55,800 = 24·9	55,300 = 24·7	79,700 = 35·6	Broke in Solid. Do.
203	Double Weld (Lap) H	3·02 x ·72 3·00 x ·37	3·00 — 3·00	86,400 = 38·6	86,400 = 38·6	100,900 = 45·0	Broke at Weld
204	Single (Lap) I	2·96 x ·83	3·00 — 2·95	99,000 = 44·2	99,000 = 44·2	106,800 = 47·7	Broke at Weld
205	Welded at Four Positions J	4·02 x ·75	——	96,500 = 43·1	——	104,100 = 46·5	Broke at Weld

Table 3—Results of Tests of Specimens Shown in Fig. 2

is not appreciably affected by heat treatment (unless very rapid cooling is used), the details of the previous treatment could not be ascertained by this examination. It appeared that the whole plate had been heated above the critical range after rolling, or alternatively that the final rolling had been stopped while the plate was still above the critical range. Three areas of the plate were examined, viz., at the end farthest from the weld, at the fracture and under the weld. No appreciable difference in structure could, however, be detected. The operation of welding had, therefore, not produced any change in the microstructure of the steel either at or near the weld, and there was nothing in the structure to suggest why the plate broke at a particularly low load.

A further possible explanation of the failure is the unequal distribution of stress in this type of specimen, and two similar specimens made from steel of structural quality are being made and tested to settle this point.

Part III—Program of Future Work

The research program consists of three items:

(*a*) Investigation of field tests for a welded joint

(*b*) Statistical series of mechanical tests on joints

(*c*) Research on (1) design of welded joints and (2) the effect of rigidity of joints on the stress distribution.

(*a*) If a non-destructive test could be evolved which would give a reliable indication of the strength of a welded joint, the major problem of the use of arc welding in structural work would be solved. Although one or two of the methods that have been suggested or tried may be slightly more promising than others, there is apparently only a remote chance of success. While, therefore, this line of investigation merits further explanation, it would seem unwise to rely mainly upon it.

(*b*) An extensive series of mechanical tests on joints, though laborious and lengthy, must, however, lead to definite results if all the variables are taken into account in the selection of test specimens. For this reason, and because of the doubt of success in attempting to evolve a field test, it has been decided that the statistical examination should constitute the main program. This conclusion is in accord with that reached by American investigators.

Considerable attention has been devoted to the procedure to be followed and the points of technique to be studied. The specimen joints of selected types will have to be prepared by different firms, and the parts played by the skill of the individual welder, shop controls, etc., will have to be ascertained. Detailed instructions will have to be issued.

Before proceeding with the main series of tests a preliminary investigation is being made to enable the standardization of the most effective methods of preparing and testing the specimens.

(*c*) The researches on the design and strength of welds will include fatigue tests, shock tests and measurements of Young's modulus and other physical constants.

The theoretical and practical effects of rigidity of joints on the stress distribution is being included in other investigations of the Committee.

CURRENT WELDING LITERATURE

(*Continued from Dec. 1932 issue*)

Shipbuilding. Welding Longitudinal Seams of Shell Plating, L. C. Bibber. Soc. Naval Architects & Mar. Engrs.—Advance Paper no. 5, mtg. Nov. 17–18, 1932. Experimental determination of suitability of arc welding for longitudinal seams of shell plating and other strength members of ships; tests conducted by Bureau of Construction and Repair of U. S. Navy.

Spot Welding Enduro Stainless Steels, V. W. Whitmer. Welding (Sept. 1932), vol. 3, no. 9, pp. 529–530.

Spot Welding Stainless Steel Sheets, V. W. Whitmer. Heat Piping and Air Conditioning (Oct. 1932), vol. 4, no. 10, p. 669. Corrosion-resistant metals of various kinds used extensively in ducts for ventilating and exhaust systems where battery fumes, plating-room vapors, exit gases from acid processes, etc. are handled; among metals used are stainless steels; process for spot welding; reducing depression in sheet; oxide formed is surface condition.

Stainless Steel. Welding of Stainless-Clad Steel, S. L. Ingersoll. Welding Engineer (Oct. 1932), vol. 17, no. 10, pp. 27–28.

Steam Condensers. All-Welded Steel Condensers, C. F. Fox. Power (Nov. 1932), vol. 76, no. 5, pp. 230–231. Replacement of castings by steel plates, arc-welded, made gross saving of 41% in cost of construction of surface condenser for 35,000-kw. turbine.

Steam Pipe Lines. Erecting High-Pressure, High-Temperature Steam Line at West Va. Pulp & Paper Co., H. C. Schramm. Heat Piping and Air Conditioning (Sept. 1932), vol. 4, no. 9, pp. 598–601.

Street Railroad Tracks. Saving by Welding, L. T. Botto. Elec. Traction (July 1932), vol. 28, no. 7, p. 283. Methods of joint welding employed by San Antonio Public Service Co.; Thermit welding and seam weld; cost analysis in table.

Street Railroad Tracks. "Under-Traffic" Welding Prevents Delays, W. E. Bobbitt. Elec. Traction (Nov. 1932), vol. 28, no. 11, pp. 444–445. Joint welding methods which eliminated night work, reduced delays and lowered maintenance costs for Virginia Electric & Power Co.

Stress Determination Is Imperative in Welding Design, R. E. Kinkead. Machine Design (Oct. 1932), vol. 4, no. 10, pp. 33–35. Suggestions to accommodate stresses without reference to method of fabrication, and to place welds later; importance of position and contour of fillets.

Structural Welding, S. Couzin. S. African Instn. Engrs. Jl. (July 1932), vol. 30, no. 12, pp. 320–324; also (Aug. 1932), vol. 31, no. 1, pp. 13–15.

Structural Steel. Design of Welded Structures, C. Helsby. Structural Engr. (Nov. 1932), vol. 10, (New Series) no. 11, pp. 463–471. General review of modern practice; method of reducing cross section of column and bracketing; method of fabricating stanchion bases.

Structural Steel. Distribution of Shear in Welded Connections, H. W. Troelsch. Am. Soc. Civ. Engrs.—Proc. (Nov. 1932), vol. 58, no. 9, pp. 1499–1506. Mathematical analysis of distribution of shearing stresses along length of longitudinal fillet welds that are continuous over entire length of lap joints.

Testing of Fusion Welds in Laboratory, L. W. Schuster. Welding Jl. (Sept. 1932), vol. 29, no. 348, pp. 262–269; and (Oct.), no. 349, pp. 294–298.

Tubes. Structure of Welded Tubes Made of Steel Strip, J. S. Adelson. Metal Progress (Nov. 1932), vol. 22, no. 5, pp. 37–40.

Vacuum Tubes. Lead-in Wires for Vacuum Tubes, T. F. Faulhaber. Wire (Nov. 1932), vol. 7, no. 11, pp. 379–381 and 402.

Water Pipe Lines. Japanese Install Equipment for Welded Pipe, M. Taylor. Welding (Oct. 1932), vol. 3, no. 10, pp. 577–578. Welding methods and equipment at Kawasaki Dockyard Co., in Kobe, for production of water pipe of 1300, 1500 and 2100 mm. in diam. and about 6 mm. in length.

Waterwheels. Electric Welding Repairs Waterwheel Runners, M. O. McKinney. Elec. World (Nov. 5, 1932), vol. 100, no. 19, pp. 622–623.

X-Ray Analysis. Examination of Welds with X-Ray, E. W. Page. Welding (Sept. 1932), vol. 3, no. 9, pp. 527 and 547.

X-Ray Analysis. Radiographic Examination of Welds, R. A. Stephen. Machy. Market (Nov. 11, 1932), no. 1671, pp. 15–16.

X-Ray Analysis. Radiographic Examination of Welds, R. A. Stephen. Welding Jl. (Oct. 1932), vol. 29, no. 349, pp. 299–303; see also Sheet Metal Industries (Nov. 1932), vol. 6, no. 7, pp. 451–454. Use of portable X-ray equipment for testing seams in boilers and pressure vessels.

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